SRC
Saskatchewan
Research Council

Saskatchewan
Energy and Mines

Saskatchewan
Geological Survey

QUATERNARY GEOLOGY AS A GUIDE TO MINERAL EXPLORATION IN THE SOUTHEASTERN SHIELD, SASKATCHEWAN

by

B.T. Schreiner

1986

Saskatchewan Research Council

Technical Report No. 189

Saskatchewan Energy and Mines

Open File Report No. 86-5

Although the Saskatchewan Research Council has exercised all reasonable care in the compilation, interpretation and production of this report, it is not possible to insure total accuracy, and all persons who rely on the information contained herein do so at their own risk. The Saskatchewan Research Council, the Department of Energy and Mines, and the Government of Saskatchewan do not accept liability for any errors, omissions or inaccuracies that may be included in this report or any interpretations derived from it.

This report was prepared by the Sedimentary Resources Program of the Resources Division, Saskatchewan Research Council under a joint venture agreement with the Saskatchewan Geological Survey of the Department of Energy and Mines.

Research initiated September 1985.
Manuscript completed August 1986.
Typeset October 1986.
Printed November 1986.

Front cover: Gold grain panned from the "Riddle Till" derived from the EP Zone, Waddy Lake, Saskatchewan. Actual size (0.5 x 1.5 mm)

(photograph courtesy of J.E. Campbell, Saskatchewan Research Council)

FOREWORD

This report has been generated in response to the current resurgence of exploration interest in Saskatchewan, particularly in the gold-bearing areas in the southeastern Shield. Drift prospecting in Saskatchewan is in its infancy but will continue to grow as the method becomes better understood and there is more emphasis on discovery of buried deposits. This report brings together information from various sources and establishes the Quaternary geological setting and stratigraphy in order to provide a framework and guideline for effective drift prospecting especially for gold. The distribution of the Quaternary units is shown on generalized maps together with lithological and geochemical characterization and descriptions of type localities. The relationship between the distribution of gold in the Quaternary deposits to the types of gold deposits in the belt is demonstrated by some typical cases of drift anomalies such as till dispersal fans within the study area. These cases also illustrate the methodology and application of Quaternary geology to locating mineral deposits. The report includes recommendations for future work to establish the Quaternary geology data base and suggestions for problem solving and further exploration. It is anticipated that the report will serve as a guide to the use of Quaternary geology in mineral exploration in the southeastern part of the Precambrian Shield area of Saskatchewan.

This report was prepared by the Saskatchewan Research Council under a joint venture agreement with Saskatchewan Energy and Mines, Saskatchewan Geological Survey. Contributory funds to support the project were derived from the Canada-Saskatchewan Agreement on Mineral Exploration 1984-89, administered by Saskatchewan Energy and Mines. All aspects of production have been handled by the Saskatchewan Research Council.

R.G. Arnold, Director
Resources Division
Saskatchewan Research Council

J.E. Christopher, Director
Saskatchewan Geological Survey

October, 1986

ACKNOWLEDGEMENTS

This project could not have been completed without the generous help and cooperation of others. The author thanks the various mining and exploration companies operating in Saskatchewan for their assistance in supplying data, information and reports which provided background for this study. Janet Campbell provided assistance in searching and data compilation, and contributed information and suggestions concerning drift prospecting and analytical techniques. Drs. R.G. Arnold and R. Macdonald reviewed the manuscript and provided valuable corrections and advice. Gwen Calderon typed the original manuscript, which was proofread by Bill Taylor, who prepared it for typesetting. Carlos Sardinha drafted the figures and along with Bryce Erikson assisted with the design and production of the cover and the final layout and production of the report. Ann Fuzesey and Virginia Harris of Saskatchewan Energy and Mines provided access to files and kindly assisted in searching and extracting information from them. Finally, I wish to thank my colleague Vladimir Sopuck for sharing his knowledge and experience through numerous discussions which provided information about drift geochemistry and insight into exploration methodology and problems.

Bryan T. Schreiner
Resources Division
Saskatchewan Research Council
November, 1986.

ABSTRACT

The main focus for gold exploration in Saskatchewan lies in the southeastern part of the Precambrian Shield between La Ronge, Reindeer Lake and Flin Flon. The general Quaternary stratigraphy of this region is: lower till (at the base) overlain by stratified sand and gravel and/or silt and clay, an upper till and an upper stratified drift.

The lower till is the most favourable sampling medium, and is widespread except where eroded by glaciofluvial or fluvial channels. The silts and clays of glacial Lake Agassiz are an impediment to surficial geochemical and biogeochemical surveys. Where they occur, commonly below an elevation of 427 m, there are very few known gold prospects. The upper till, produced during a glacial re-advance, is an unreliable sampling medium.

Studies of gold in tills show the gold to be fine-grained and delicate to irregular in shape, signifying short transport. As the gold is rarely associated with other minerals (which have generally been destroyed by postglacial oxidization), the gold itself is its own best pathfinder in drift prospecting.

Till dispersion trains are best defined by heavy mineral assays and gold particle counts from bulk till samples (>4 kg.). Gold content and lengths of the trains are higher where the mineralization occurs in more easily eroded bedrock and where they lie parallel to the train. Gold counts and dispersion patterns are also related to the dynamics of the ice sheet.

A weak correlation exists between the gold content of the heavy minerals, clay and -180 μm fractions. Background counts for the clay and -180 μm fractions are commonly 20 ppb and 5 ppb respectively. Where gold assays are high and no visible gold is seen, the gold may be very fine-grained or occluded.

It is estimated that little (<6%) of the silt and clay-sized gold is lost during heavy mineral separation of tills, and analyses of normalized gold content and gold counts can be more readily duplicated than for the clay fraction.

Geochemical analysis of till fractions not only give the gold content of the till, but also help to determine the type of mineralization of the source deposit.

Establishing the regional Quaternary geology setting together with heavy mineral assays and gold particle counts in bulk till samples is effective in defining dispersion trains which can be traced to source deposits of gold.

Keywords: Quaternary Geology, Precambrian Shield, Gold Exploration, Northern Saskatchewan, Drift Prospecting, Heavy Minerals, Gold Grains, Dispersion Trains.

Schreiner, B.T., 1986. Quaternary geology as a guide to mineral exploration in the southeastern Shield, Saskatchewan. Saskatchewan Research Council, Technical Report No. 189.
Also published as: Saskatchewan Energy and Mines, Open File Report 86-5.

CONTENTS

FOREWORD
ACKNOWLEDGEMENTS
ABSTRACT
CONTENTS
INTRODUCTION 1
- Purpose of this Review 1
- Present Study 1
- Previous Work 1
- Precambrian Bedrock 3
- Physiography 4
- Drainage 6

SOILS 6
- Soil Formation 6
- Soil Types and Classification 8

GLACIAL PROCESSES 9
- General Remarks 9
- Glacial Flow 9
- Glacial Erosion 9
- Glacial Transport 11
- Glacial Deposition 11
- Ice-movement Indicators 13
- Postglacial Erosion 13

QUATERNARY DEPOSITS 14
- Regional Distribution 14
- Glacial Landforms 15
- Proglacial Landforms 15

SURFICIAL SEDIMENTS 16
- Glacial Sediments 16
- Sandy Till 16
- Silty Till 17
- Clayey Till 17

PROGLACIAL SEDIMENTS 19
- Fluvial Sand and Gravel 19
- Fluvial and Lacustrine Sands 19
- Glaciolacustrine Silt and Clay 19

POSTGLACIAL SEDIMENTS 20
- Colluvium 20
- Lacustrine Silt and Clay 20
- Peat 22

DRIFT STRATIGRAPHY 22
- Stratigraphic Framework 22
- Glacial Stratigraphy 23
- Stanley Mission 23
- Otter Rapids 23
- Deschambault Lake 23
- Jaysmith Lake 23
- Mirond Lake 23
- Missinipe 23
- Rabbit Creek 25
- Proglacial Stratigraphy 25
- Postglacial Stratigraphy 25
- Stratigraphic Correlation 25
- Stratigraphic Interpretation 26

QUATERNARY HISTORY 27
- Introduction 27
- Phase 1 - Deglaciation History 27
- Phase 2 - Deglaciation History 27
- Phase 3 - Deglaciation History 28
- Phase 4 - Deglaciation History 29

DRIFT PROSPECTING - POTENTIAL, PROCEDURES, AND PROBLEMS 31

GEOCHEMISTRY 31

NATURE OF GOLD IN DEPOSITS AND RELATED TILL 32

DISPERSION TRAINS 32

GOLD ANALYSES IN TILL DEPOSITS 33

PROBLEMS AND SOLUTIONS FOR THE EXPLORATIONIST 34

DISCUSSION AND RECOMMENDATIONS 35

REFERENCES 37

FIGURES

Figure 1.	Location of study area.	2
Figure 2.	Generalized bedrock geology of the study area.	3
Figure 3.	Physiography and drainage of the study area.	4
Figure 4.	Oblique aerial photograph showing surface expression in the Kazan Upland.	5
Figure 5.	Photograph showing local rugged relief in the Kazan Upland.	5
Figure 6.	Soil profiles.	7
Figure 7.	Glacial process - form model.	9
Figure 8.	Roche Moutonnee formation.	9
Figure 9a.	Striated and polished stoss (up ice side) of a roche moutonnee.	10
Figure 9b.	Eroded and plucked lee (down ice side) of a roche moutonnee.	10
Figure 10.	Ground moraine and end moraine formation.	11
Figure 11.	Theoretical stratigraphic sequences.	12
Figure 12.	Surface Quaternary geology for the southeastern Precambrian Shield.	14
Figure 13.	Sandy till derived from Precambrian basement rocks.	18
Figure 14.	Mean grain-size graphs for sandy till.	16
Figure 15.	X-ray diffractograms for each of the major surficial sediment types.	17
Figure 16.	Mean grain-size graphs for silty till.	17
Figure 17.	Mean grain-size graphs for clayey till.	17
Figure 18.	Mean grain-size graphs for sand and gravel.	19
Figure 19.	Transgressive onlap (fining upward) sequence in Lake Agassiz sediments near Brabant Lake.	18
Figure 20.	Mean grain-size graphs for silt.	20
Figure 21.	Mean grain-size graphs for clay.	20
Figure 22.	Lithologic logs of lake sediments overlying till or bedrock.	21
Figure 23.	Lithologic logs and exposures of till overlying lacustrine and fluvial sediments.	24
Figure 24.	Phase 1 of the history of deglaciation about 10,000 years ago.	27
Figure 25.	Phase 2 of the history of deglaciation about 9,700 years ago.	28
Figure 26.	Phase 3 of the history of deglaciation about 9,500 years ago.	28
Figure 27.	Phase 4 of the history of deglaciation about 9,000 years ago.	29

TABLES

Table 1.	Grain-size analyses for surficial sediment samples.	16
Table 2.	Significant radiocarbon dates.	30

INTRODUCTION

Purpose of this review

At present the southeastern portion of the Precambrian Shield is the main focus for gold exploration in Saskatchewan (Fig. 1,2). In this area, surface geochemical surveys are continuing to play an important part in exploration. These surveys, including soil and biogeochemical sampling, are usually dependent on the presence of bedrock or locally derived till at or near the surface. Glaciolacustrine silts and clays related to glacial Lake Agassiz cover a significant portion of the area and are a serious impediment to exploration. Glaciofluvial material occurs as a masking veneer over smaller areas, and within channels, where till deposits may be scoured away.

Almost all known gold mineralization has been found through showings in outcrop or anomalous expressions in basal till. The areas covered by fluvial and lacustrine deposits are essentially unexplored.

Recently overburden drilling programs employing portable drilling equipment have been used to penetrate the masking layers, but these programs are plagued by the difficulty of drilling through boulder lags, the inconsistency in obtaining a representative sample, and often the absence of till, particularly in glaciofluvial channels.

The selection of a geochemical survey method is dependent to a large degree on the nature of the overburden cover; therefore, the first part of this report will deal with the Quaternary geology of the gold area. The second part will deal with the nature and distribution of gold in surface till samples, and describe some typical dispersion trains or fans which are representative of gold distribution in the drift of the area. The third part is a review and discussion of problems of interpretation facing explorationists using Quaternary deposits as a guide to mineral deposits particularly gold. Recommendations are included to attempt to improve the effectiveness of drift prospecting for gold in Saskatchewan.

Present Study

The first systematic reconnaissance study of the Quaternary geology of the Precambrain Shield of Saskatchewan was carried out between 1974 and 1980 (Schreiner, 1984 and Schreiner, et al., 1984). Twenty maps at a scale of 1:250 000, together with a computer printout of site specific data, document the surficial geology and basic stratigraphy while a comprehensive report including a 1:1 million scale map summarizes the geology on a regional scale. The maps and reports available do not provide the detail necessary to evaluate the most suitable geochemical survey to use on any one grid; however, the information provides a model or framework of information within which more detailed exploration projects can be developed.

On a more local scale, investigations have been conducted in the Waddy Lake area in the northwest part of this study area. Overburden Drilling Management Ltd. under contract from Waddy Lake Resources carried out a detailed overburden sonic drilling program which led to the discovery of the EP gold zone (Averill and Zimmerman, 1984). The regional Quaternary geology and stratigraphy for this area along with specific cases of gold grain dispersion studies at Waddy, Tower and Star Lakes was studied by Sopuck et al. (1986). More detailed mapping of the Quaternary geology and investigations of the nature of the till deposits in respect to their potential for drift prospecting has been done in the Waddy Lake area (Campbell, 1986). These works form the main basis for this present review.

Previous Work

Upham (1895), Tyrrell (1896), W.A. Johnston (1916 and 1946) gave detailed descriptions of the lake sediments, landforms, and history of Lake Agassiz, the northern part of which extends into the study area. Elson (1967) summarized this information, as well as data obtained by himself and other workers, in a comprehensive account of the history of Lake Agassiz.

Kupsch (1969) provided a short note, together with aerial photographs and a glacial geology map of Saskatchewan presenting on a larger scale, the glacial features already shown by Prest et al. (1968). Kupsch (1975) also described the physiography, erosion, and deposition in preglacial, glacial, and postglacial time for a large area of the Churchill River drainage basin in Saskatchewan.

Langford (1975) provided notes on the geology of the Churchill River basin. These reports, together with a more recent paper (Langford, 1977) deal with the glacial geology and particularly with beaches, lake levels, and other apsects of Lake Agassiz.

W.G.Q. Johnston (1978) provided a brief report locating, describing and explaining Quaternary features noted during 10 years of mapping the bedrock in the vicinity of Reindeer Lake and Reindeer River. Much of his work deals with the sediments, beaches, and the extent of Lake Agassiz.

Geologists of the Saskatchewan Geological Survey of Saskatchewan Energy and Mines have mapped most of the bedrock of northern Saskatchewan. Some information about the Quaternary geology is included in almost all reports.

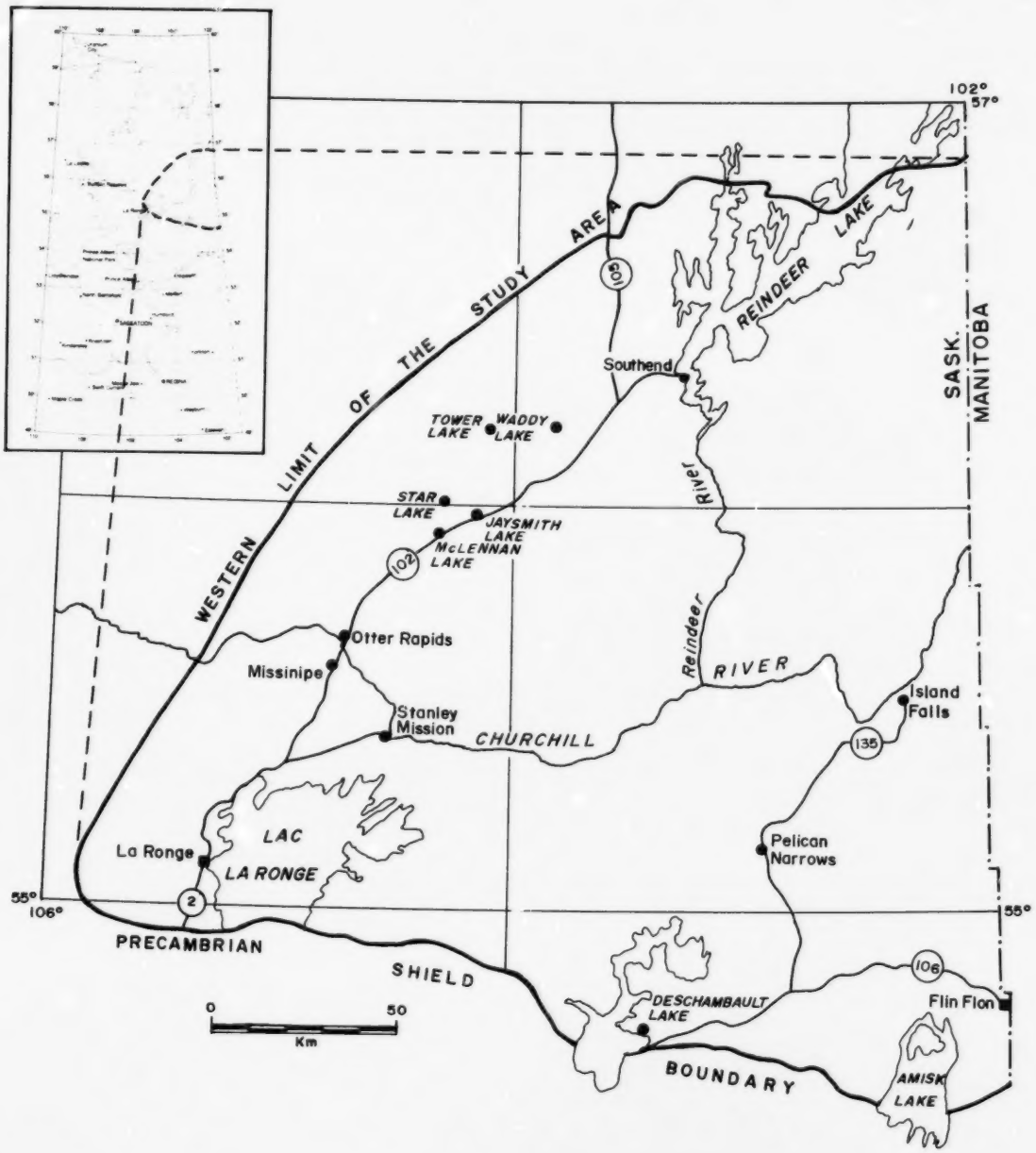


Figure 1. *Location of study area. Major roads, settlements and investigation sites referred to in this report are identified.*

Precambrian Bedrock

The Precambrian geology has been categorized and summarized by Lewry and Sibbald (1977,1980) and Lewry et al. (1978), and compiled at 1:1 million scale by Macdonald (in Macdonald and Broughton, 1980). These crystalline bedrocks comprise variously metamorphosed granitoids, metavolcanics and other supracrustal rocks within the Trans-Hudson Orogen produced mainly during the Early Proterozoic 1900 to 1750 Ma ago (Fig. 2). A pronounced northerly to northeasterly structural trend in some parts of the area coincides with a strong topographic macro-fabric.

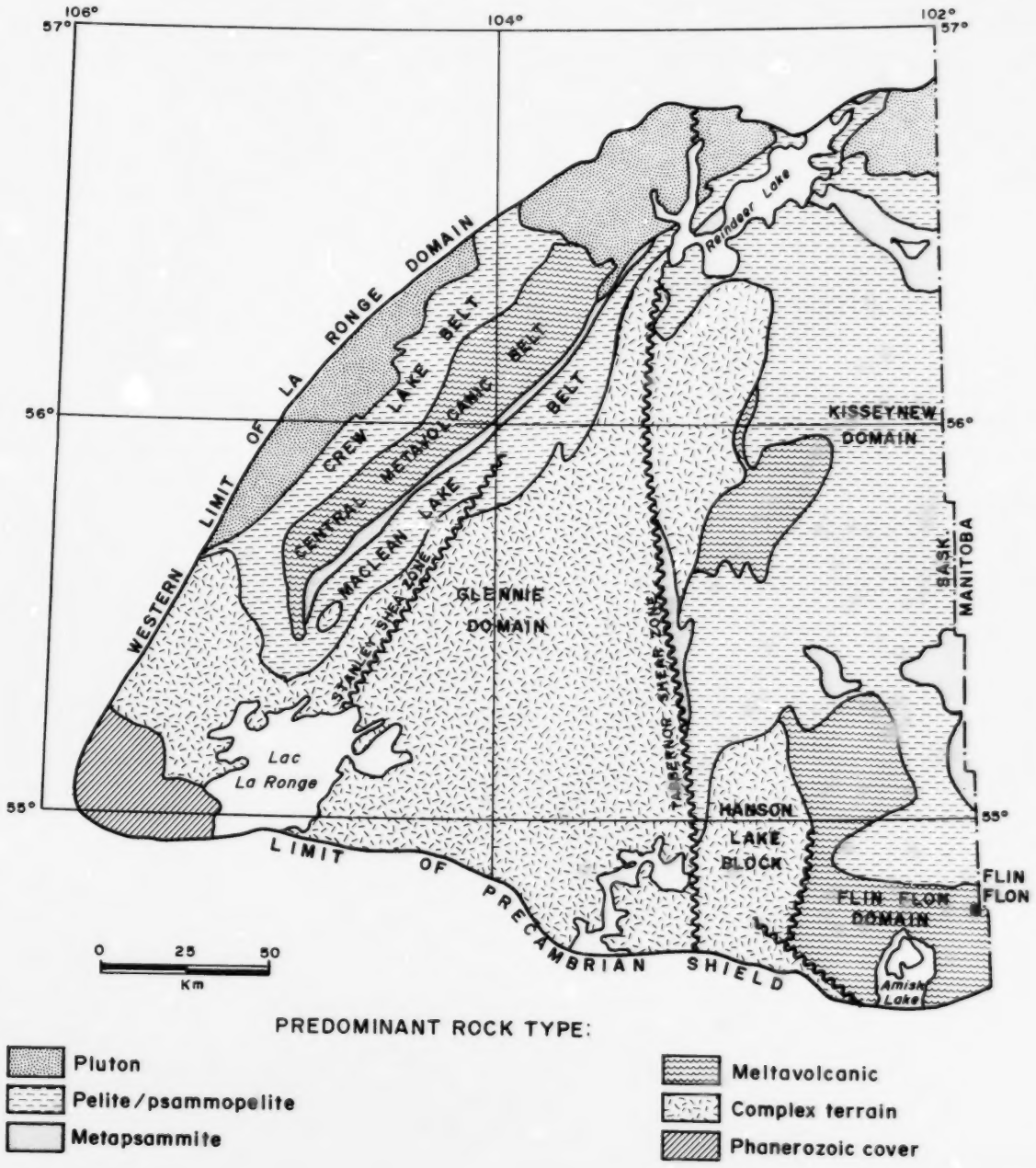


Figure 2. *Generalized bedrock geology of the study area in the southeastern portion of the Saskatchewan Precambrian Shield. The "complex terrains" include plutonic and supracrustal units. The Central Metavolcanic Belt contains about 40 percent plutons. The La Ronge Domain comprises all terrain west of the Stanley Shear Zone and its northerly extension. (by R. Macdonald).*

Physiography

The study area lies almost entirely within the extensive Kazan Region (Bostock, 1970), which comprises the Precambrian Shield area and is bordered to the south by the Interior Plains (Fig. 3). The Kazan Region in Saskatchewan is composed of the Kazan Upland.

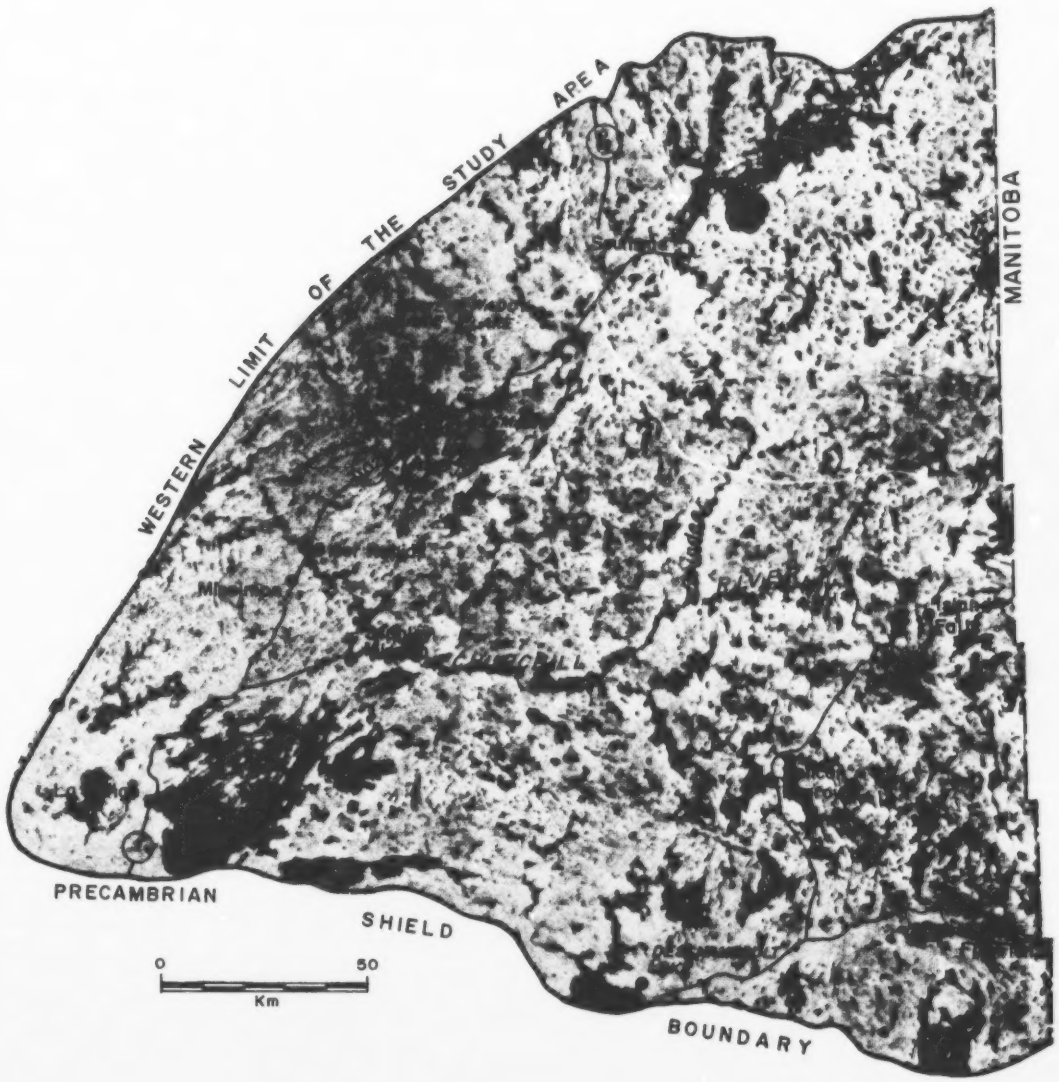


Figure 3. *Physiography and drainage of the study area in the southeastern portion of the Saskatchewan Shield.*

The Kazan Upland is developed on the crystalline basement rocks of the Precambrian Shield. The topography of the area is typical of the Canadian Shield with extensive areas of rock, forming broad, smooth uplands and lowlands. The landscape appears to have an expressionless, monotonous, nearly planar skyline (Fig. 4). In detail, however, the surface is extraordinarily uneven with relief up to 90 m, but generally less than 60 m. Lakes, swamps, and muskeg fill the valleys and depressions between the ridges, hills, and knolls (Fig. 5).

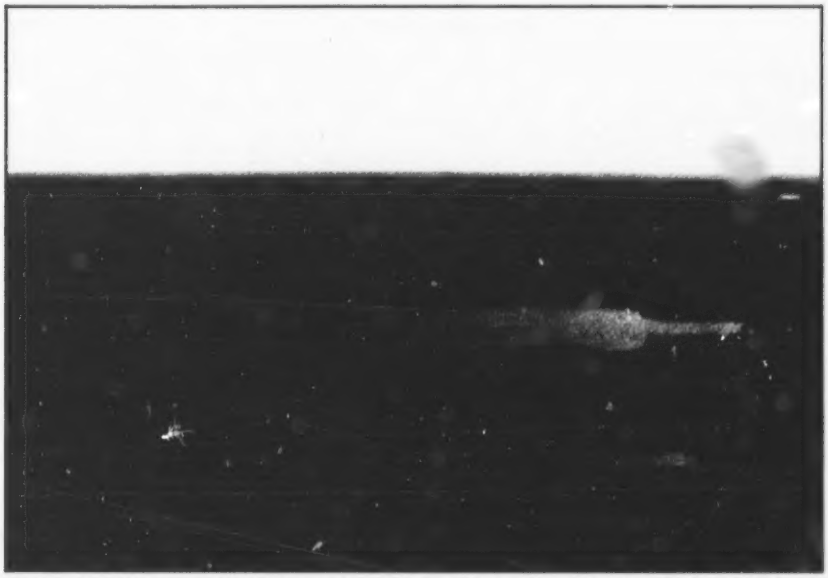


Figure 4. *Oblique aerial photograph showing surface expression in the Kazan Upland.*

Figure 5. *Photograph showing local rugged relief in the Kazan Upland.*

Regionally, the first order relief shows a smooth, gently rolling landscape. The surface slopes gradually to the southeast from an average elevation of 500 m in the west to 400 m in the east.

The intricate second order relief consists of a series of ridges, valleys, and shallow basins. Folding, faulting, and fracturing of the rock is responsible for much of this relief, whereas other ridges and valleys are related to differential erosion of the variable bedrock lithology. Glacial ice, in turn, scoured out low-lying areas, especially in zones of more easily eroded rock, and thus enhanced the details of relief. Simultaneously, the ice smoothed and polished the faces and crests of resistant bedrock knobs and hills while plucking rock from the lee sides. Generally, the bedrock structure and lithologic trends are parallel to the direction of ice movement. This caused the glacial mass to "etch" out and smooth bedrock features which most likely were originally much more rugged. Some of the bedrock relief has been masked by overburden. However, commonly the bedrock relief is revealed through a thin veneer of glacial material.

Drainage

Most of the area drains east to Hudson Bay via the Churchill and Nelson Rivers. The Churchill River, the longest waterway, drains the central part of the area. It flows along the contact of the Phanerozoic sedimentary rocks and the Precambrian Shield in the west before cutting across the Shield east of Pinehouse Lake. The southern part drains southward to the Saskatchewan River which flows northeast across the Interior Plains (Fig. 3).

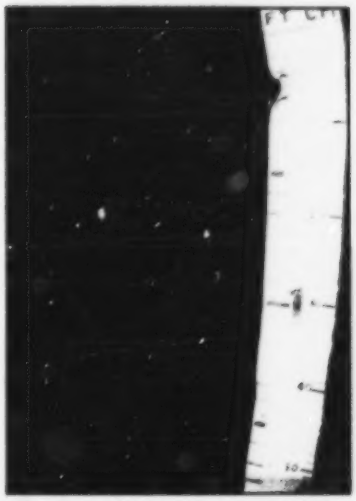
The development of drainage on the Shield through geologic time is discussed in detail by Robertson (1978). The present drainage pattern is strongly influenced by bedrock in northern Saskatchewan. The Shield area exhibits long, narrow, ragged lakes, mostly parallel to the bedrock structure. The Churchill River is an excellent example of this pattern where it traverses the Shield. The river itself is a series of long, narrow lakes linked by fast-flowing rivers, with rapids and falls. The lakes are parallel to bedrock structure and ice-flow direction. This pattern is repeated over the entire Shield area and results in a trellis-like drainage pattern with many rivers flowing parallel in a northeast-southwest direction. Connecting these rivers are short streams generally at right angles to the main flow and following joint patterns or other weaknesses in the bedrock. Perched muskeg are numerous but generally small in area. As much as 35 to 40 per cent of the Shield area may be covered by water.

SOILS

Soil Formation

The soils of the Precambrian Shield area of northern Saskatchewan were classified as dominantly Podzolic soils by J.S. Clayton et al. (1977). Until recently little work has been done on soils covering the Shield. Several profiles were sampled by D.F. Acton, G.A. Padbury, (Saskatchewan Institute of Pedology) and R.J. St. Arnaud, (University of Saskatchewan) during their work in conjunction with the Quaternary mapping program. These data provide the basis of soil information within the study area. Types and classification of soils in Canada are provided by J.S. Clayton et al. (1977) and the Canada Soil Survey Committee (1978).

All soil profile development is related to the main soil-forming factors of: parent material, relief, climate vegetation, organisms, and time. In northern Saskatchewan the parent materials range from very sandy to silty and clay-rich and are commonly noncalcareous with massive to friable structures. The nearly level to very strongly rolling relief ranges from well-drained to poorly drained. Forest vegetation dominates in this subhumid continental climate. The main soil forming process is lessivation (leaching). This process results in grey surface layers below leaf or peat litter with removal of organic matter and soluble minerals from the surface. Commonly, translocation of clay and alteration and removal of minerals from the surface and accumulation at depth occurs. This soil-forming action governed by local factors, such as relief, parent material and vegetation, results in six significant soils in the study area. Brunisolic, Luvisolic, and Podzolic soils (Canada Soil Survey Committee, 1978) are developed on well-drained uplands. These are the most common soils in the study area and are considered in more detail below. Typical profiles are shown in Figure 6. Gleysolic and organic soils are confined to poorly drained areas and are associated with peat deposits. Regosolic soils are related to unstable areas such as slumps and dunes, or to recent deposits, such as flood plains.



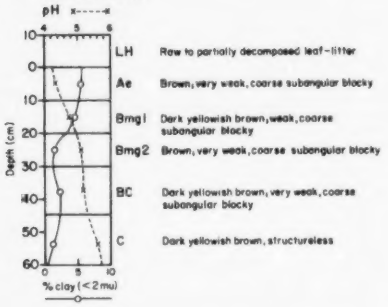
6A. *Typical Degraded Dystric Brunisol*

6B. *Typical Orthic Gray Luvisol*

6C. *Typical Humo-Ferric Podzol*

Lac La Ronge (73 P)
- along Hwy 102 north of La Ronge

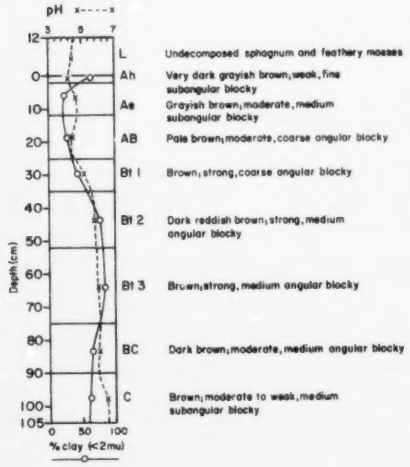
Gleyed Degraded Dystric Brunisol
on Sandy Glacial Till
(IP-75-003)



LH — Raw to partially decomposed leaf-litter
Ae — Brown, very weak, coarse subangular blocky
Bmg1 — Dark yellowish brown, weak, coarse subangular blocky
Bmg2 — Brown, very weak, coarse subangular blocky
BC — Dark yellowish brown, very weak, coarse subangular blocky
C — Dark yellowish brown, structureless

Lac La Ronge (73 P)
- along Hwy 102 at Lynx Lake

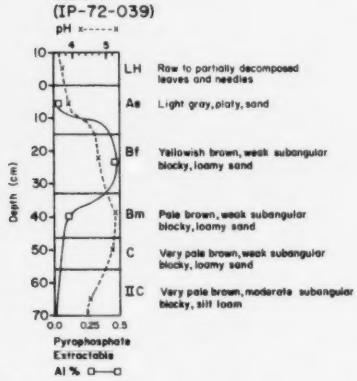
Orthic Gray Luvisol on
Glaciolacustrine Clay
(IP-75-004)



L — Undecomposed sphagnum and feathery mosses
Ah — Very dark grayish brown, weak, fine subangular blocky
Ae — Grayish brown, moderate, medium subangular blocky
AB — Pale brown, moderate, coarse angular blocky
Bt 1 — Brown, strong, coarse angular blocky
Bt 2 — Dark reddish brown, strong, medium angular blocky
Bt 3 — Brown, strong, medium angular blocky
BC — Dark brown, moderate, medium angular blocky
C — Brown, moderate to weak, medium subangular blocky

Mudjatik (74 B)
- south of Black Birch Lake

Orthic Humo-Ferric Podzol on
Glacial Till
(IP-72-039)



LH — Raw to partially decomposed leaves and needles
Ae — Light gray, platy, sand
Bf — Yellowish brown, weak subangular blocky, loamy sand
Bm — Pale brown, weak subangular blocky, loamy sand
C — Very pale brown, weak subangular blocky, loamy sand
IIC — Very pale brown, moderate subangular blocky, silt loam

Figure 6. *Soil profiles. Provided by D.F. Acton and G.A. Padbury, Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, Saskatchewan.*

Soil Types and Classification

Brunisolic soils are developed on the more permeable glaciofluvial, sandy glaciolacustrine, and glacial till deposits in well drained forested locations. The main characteristics of these soils are the presence of a weakly developed Ae horizon, separating an organic (LH) layer at the surface from an underlying B horizon, which shows no distinct accumulation of weathering products. The parent material, (C) horizon, is commonly structureless and noncalcareous. The terms Dystric and Eutric are applied to the classification according to the degree of acidity; and Eluviated indicates that leaching was active in producing the Ae horizon. Most of the Brunisols are Eluviated Dystric Brunisols.

Luvisolic profiles are developed on less permeable materials, such as glaciolacustrine or glacial till deposits with high silt and clay content, under well-to-imperfectly-drained forested conditions. The general characteristics of thesé soils in this area are a well developed mat (LH) layer of organic debris, a weak or absent organic (Ah) horizon, a well developed eluviated (Ae) horizon, and a (Bt) horizon of clay accumulation. The parent material is commonly noncalcareous, massive silt or clay. Most of the Luvisols are Orthic Gray Luvisols, indicating a weakly developed or absent organic (Ah) horizon.

Podzolic soils are developed on glacial till and glaciofluvial parent material with a high silt content in moderately-well-drained locations under black spruce forest or moss cover. These soils commonly contain a leaf-litter horizon (LH) underlain by a well developed, eluviated, or leached (Ae) horizon. The B horizon shows as accumulation of iron and aluminum colloids with little organic matter (Bf). The parent material is commonly massive and noncalcareous. Most of these podzols are classified as Orthic Humo-Ferric Podzols.

GLACIAL PROCESSES

General Remarks

Continental glaciers advanced and retreated across the study area several times during the Quaternary Period which spans the last two to three million years of the earth's history. The last major ice mass was the Laurentide ice sheet. Its Keewatin center of accumulation supplied the ice which flowed in a general southwesterly direction across northern Saskatchewan. The repeated glaciations resulted in erosion of the bedrock and any previously deposited glacial sediments and the deposition of ice-laid tills and water-laid gravels, sands, silts and clays.

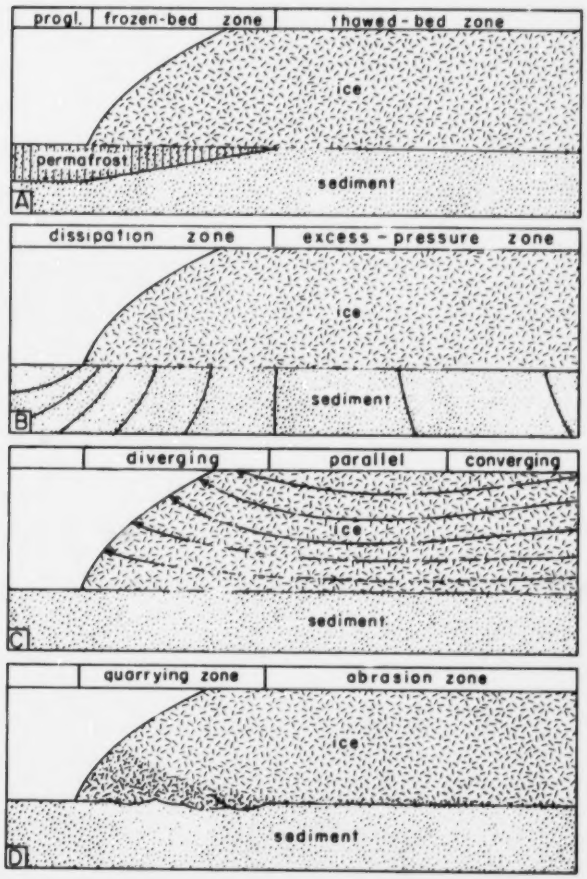


Figure 7. *Glacial process - form model. After Lee Clayton and Moran, 1974, p. 92*
A - Thermal zones
B - Groundwater pressure zones, showing isopotential lines with the potential decreasing to the left.
C - Glacial flow zones
D - Erosion zones.

Glacial Flow

An internal flow system exists within an ice mass where a series of parallel shear planes creates a laminar flow pattern (Fig. 7-C). The impetus for this flow is supplied by the gradient of the ice mass itself which is thickest at the center. The ice front may stop advancing or may be retreating, but this flow system will still be active. Only when accumulation ceases and ice becomes stagnant or dead, does the flow system stop.

Flow lines converge near the ice centre or where the ice moves downslope; this is called extending flow (Fig. 8). Parallel flow prevails in the central portion of the ice mass or where it overrides a level surface. This horizontal flow is also termed gravity or lateral flow. Diverging flow or flow upwards occurs at the ice front or where the ice moves up-slope; this is called compressive flow. The nature of the ice flow affects erosion and the resulting transport mechanism and distances that the debris is moved.

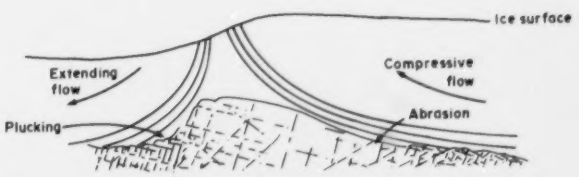


Figure 8. *Roche Moutonnee formation. Longitudinal section of a typical roche mountonnee fashioned by a glacier from an obdurate mass of sparsely jointed granite. Modified after Fairbridge, 1968, p.964.*

Glacial Erosion

Undoubtedly, the major effect of glaciation on the Precambrian rocks was glacial erosion which modified the surface to its present appearance. The ice movement was nearly parallel to the bedrock structural trend. Abrasion by the ice enhanced the topography of the bedrock by eroding low areas, especially those composed of more easily eroded rock. Stream valleys were enlarged, particularly those parallel to the glacial movement. Resistant hills and knolls were scraped and polished but remained as areas of high relief. Erratics, many perched on outcrops or partially buried in glacial drift, are evidence of the erosion and transport of fragments of bedrock by the ice.

Glacial erosion is a accomplished by plucking, quarrying, and by abrasion. Plucking is the process whereby blocks of rock are loosened and pulled away by the glacier. The plucking action results from extending flow where the ice moves down-slope over an obstruction.

Figure 9A. *Striated and polished stoss (up ice side) of a roche moutonnee.*

Figure 9B. *Eroded and plucked lee (down ice side) of a roche moutonnee.*

A good example of this effect is shown by roches moutonnees (streamlined, whaleback-shaped rock hills) where the down-ice side is eroded by plucking of rock which is pulled away from the lee or down-ice side of the rock outcrop (Figs. 8, 9).

Quarrying of material below the ice occurs primarily near the ice front where the ice is frozen to its bed (Fig. 7-D). Glacial thrusting (Kupsch, 1962; Christiansen and Whitaker, 1976) occurs where diverging flow excavates drift and/or bedrock and moves the debris up into the ice mass (Fig. 7-C). Similar quarrying results from compressive flow where ice moves up an obstruction. This quarrying is most effective in fractured or well-jointed rock.

Abrasion is the mechanical grinding, scraping, and rubbing away of rock surfaces by glaciers armed with rock particles. Abrasion and crushing of underlying material occurs in the abrasion zone. This zone corresponds to the thawed-bed zone back from the ice front where ice is sliding over the surface (Fig. 7-A,D). Abrasion and crushing also occur where the ice is in compressive flow or where it moves up an obstruction. Striations, polished surfaces, grooves, and crescentic marks are examples of abrasion (Figs. 8, 9).

Glacial Transport

Transport in the abrasion zone is confined largely to the base of the ice. Relatively little material is eroded and parallel flow does not carry the debris far up into the ice mass (Clayton and Moran, 1974). In the quarrying zone more eroded material is supplied. Diverging flow acts as a conveyor, transporting the debris up into the ice along shear planes. This debris accumulates on the ice surface and is transported as a superglacial load.

Glacial Deposition

Deposition by glacial ice which results in till deposits is described in detail by Dreimanis (1976). Basically, glacial deposition is accomplished by a process of incorporation, cycles and release of material. Subglacial material is plastered on subglacially or beneath the ice (lodgement till), whereas englacial and superglacial material is let down from the top (ablation till). Sediment enclosed at the base of the ice is laid down in the thawed-bed zone where melting permits the deposition of the debris (basal meltout till). Where the lower part of the ice is choked with sediment, deposition occurs (Fig. 10).

Subglacial till is commonly rather thin in northern Saskatchewan because little debris is available in the subglacial zone on account of the hard Precambrain rocks in a relatively flat, peneplained terrain which is difficult to erode by the glacier. The pebbles and granules in the subglacial debris are aligned parallel to, or normal to, the flow direction. Shearing of the sediments results in a sharp, truncated contact which exhibits drag or thrust features and the incorporation of older sediments into younger deposits.

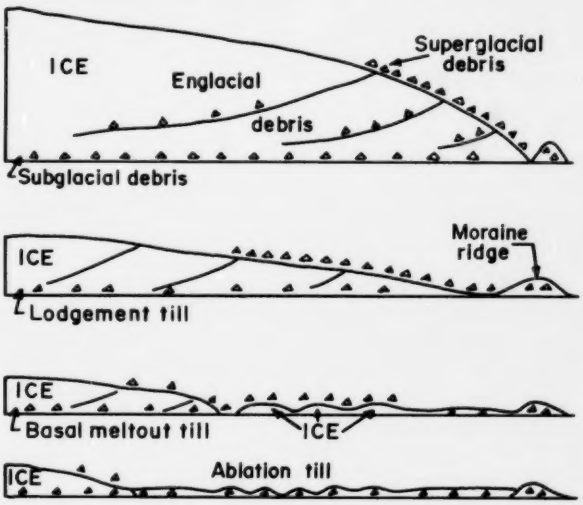


Figure 10. Ground moraine and end moraine formation. Modified after Price, 1973, p.203.

Debris eroded from beneath the ice is carried up along shear planes to the surface of the glacier. This superglacial load is most abundant near the ice front. Melting supplies water to the sediments. Mass movement of the debris down the ice slope results in an accumulation of partially washed sediment at the ice margin, commonly assuming the form of end moraines. This process is illustrated in Figure 10. Material which remains in the ice or on the ice surface is gradually let down as the stagnant ice thins. Eventually, this debris subsides and is deposited as ablation ground moraine on top of already deposited lodgement till, basal meltout till or, where such till is absent, on previously existing rocks or drift. The ablation ground moraine may have a flat, featureless upper surface, exhibit minor relief features, or may be distinctly hummocky. Ablation till normally retains little or no ice-flow fabric and is generally unconsolidated, unless it is an older deposit and has been overridden by a re-advance which would compress the debris.

This relatively simple succession of lodgement and ablation till can create a complicated stratigraphic sequence, as shown in Figure 11. Layers of till and stratified drift may be deposited in some places but be absent in others, depending on topography, the melting process, or other factors. Normally, most deposition occurs on the lee side of topographic obstructions; little debris is deposited on the side facing the ice where erosion is the dominant process. Successive ice advances erode pre-existing deposits in whole or in part and deposit more sediments similar to the first advance, resulting in a complex glacial stratigraphy. On the Shield multi-cycle drift is present in some locations whereas in others no sediments cover the bedrock, either because they were never deposited or were removed by glacial and water erosion and mass movement in postglacial time.

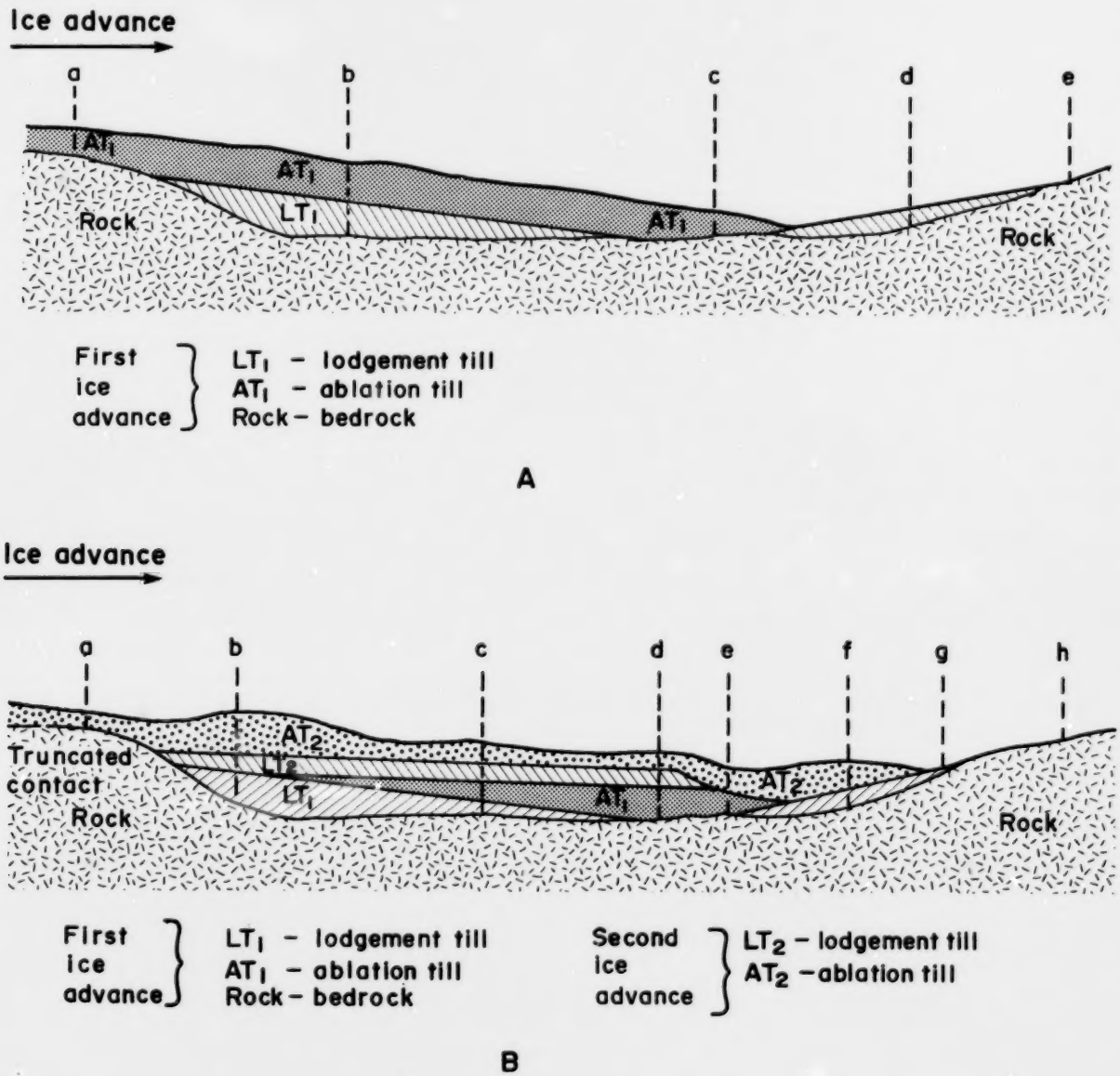


Figure 11. Theoretical stratigraphic sequences.
A. Possible stratigraphic sequences resulting from one ice advance.
B. Possible stratigraphic sequences resulting from two ice advances.

Ice-movement Indicators

The glacial ice records its movement mainly in two ways. Abrasion of bedrock by flowing ice results in striations, grooves, gouges, and crescentic marks scratched into the bedrock surface (Fig. 9). Flowing ice also molds its drift into streamline features.

Roche moutonnees and crag-and-tail features also denote the ice direction. Moreover, unlike striations, they also denote the sense of the movement rather than merely its direction. Streamlined bedrock features are common in the study area where drift is thin.

The glacier flowed radially from the Keewatin ice centre resulting in a dominant southwesterly flow direction across the study area (Fig. 12). The direction ranges from 180° azimuth near the eastern provincial boundary to about 225° on the western limit of the study area.

Although the dominant northeast to southwest direction is maintained over the area, there are other local flow directions. W.G.Q.Johnston (1978) notes northwest to westerly trending glacial striae in several localities of the southern part of the Reindeer Lake area. He concludes that these striae are older than the southwesterly trending ice movement indicators but believes them to have been formed by the last glaciation. These striations may have formed during the advance of the glacier, whereas the younger ones formed during retreat.

Schreiner and Alley (1975) record crossing striations along Highway 102 near McLennan Lake. The strongly developed striae trend from 200° to 225° azimuth. The finer, more weakly developed striae cut across the first set at directions from 245° to 260° with a maximum divergence at 290° and 310° azimuth. The origin of these later striae is not clear, but they may be related to a minor readvance of a thin ice lobe into the Lake Agassiz basin (Schreiner and Alley, 1975) or they may have been formed as W.G.Q. Johnston assumed.

Ice movement features indicate a southerly flow along the southern part of Reindeer River. Other minor variations are noted in many areas; commonly they can be attributed to an irregular rock bed. Ice is deflected or directed by valleys and uplands resulting in a "wandering" pattern of ice movement.

The age of eroded ice-movement indicators is difficult to determine. Because glacial erosion would likely obliterate most previously formed striations and grooves, the striae that can be seen in the field probably represents the last glaciation, as do drumlins and flutings. The fact that the ice direction is generally parallel to the regional structure has several implications for exploration. In particular, the glacial dispersion trains found to date are generally long and narrow and are restricted to ridge and valley topography parallel to ice direction.

Postglacial Erosion

Postglacial erosion has been slight in comparison to the earlier glacial erosion. Boulder fields or "Felsenmeer", are found in many parts of the area in topographically low areas or on crests and sides of hills. These rock fields are likely the result of frost shattering. Some chemical and mechanical erosion, mainly frost shattering, has deteriorated the bedrock, but its effects are minor and generally only the surface of outcrops is pitted or spalled off.

Surface runoff has cut into surface sediments, especially fine materials such as silts. This stream erosion, which results in trenches about 1 m deep, is best seen in ditches along roads in areas of silty deposits from which vegetation has been removed. The eroded sediments are carried to local streams and rivers and then deposited in lakes. During times of high runoff the Wathaman River is a clear stream until it flows under Highway 102. It then becomes a clouded stream that deposits a delta outlined by a plume of murky water, in Brabant Lake.

As the glacial ice retreated, melted water drained away and sediments dried out. Strong winds eroded the sandy sediments carrying away the finer-grained fractions. These sand-laden winds etched boulders and bedrock and finally the load was deposited as sand dunes and loess.

Warming resulted in the thawing of permafrost. Peat plateaus and other areas of extensive permafrost deteriorated to small isolated patches of frozen ground and wet muskeg.

QUATERNARY DEPOSITS

Regional Distribution

The distribution of surficial deposits in the area of interest in the southeastern portion of the Precambrian Shield is shown in Figure 12. Areas of thin moraine (till deposits) together with outcrop are interdispersed with large areas of glaciolacustrine material. This area contrasts with the western portion of the Saskatchewan Shield where large volumes of glacial debris were derived from the Athabasca Plain. The result is much thicker and sandier deposits of till, abundant fluvial outwash cover and the formation of numerous landforms such as drumlins and eskers which are relatively few in the area of study.

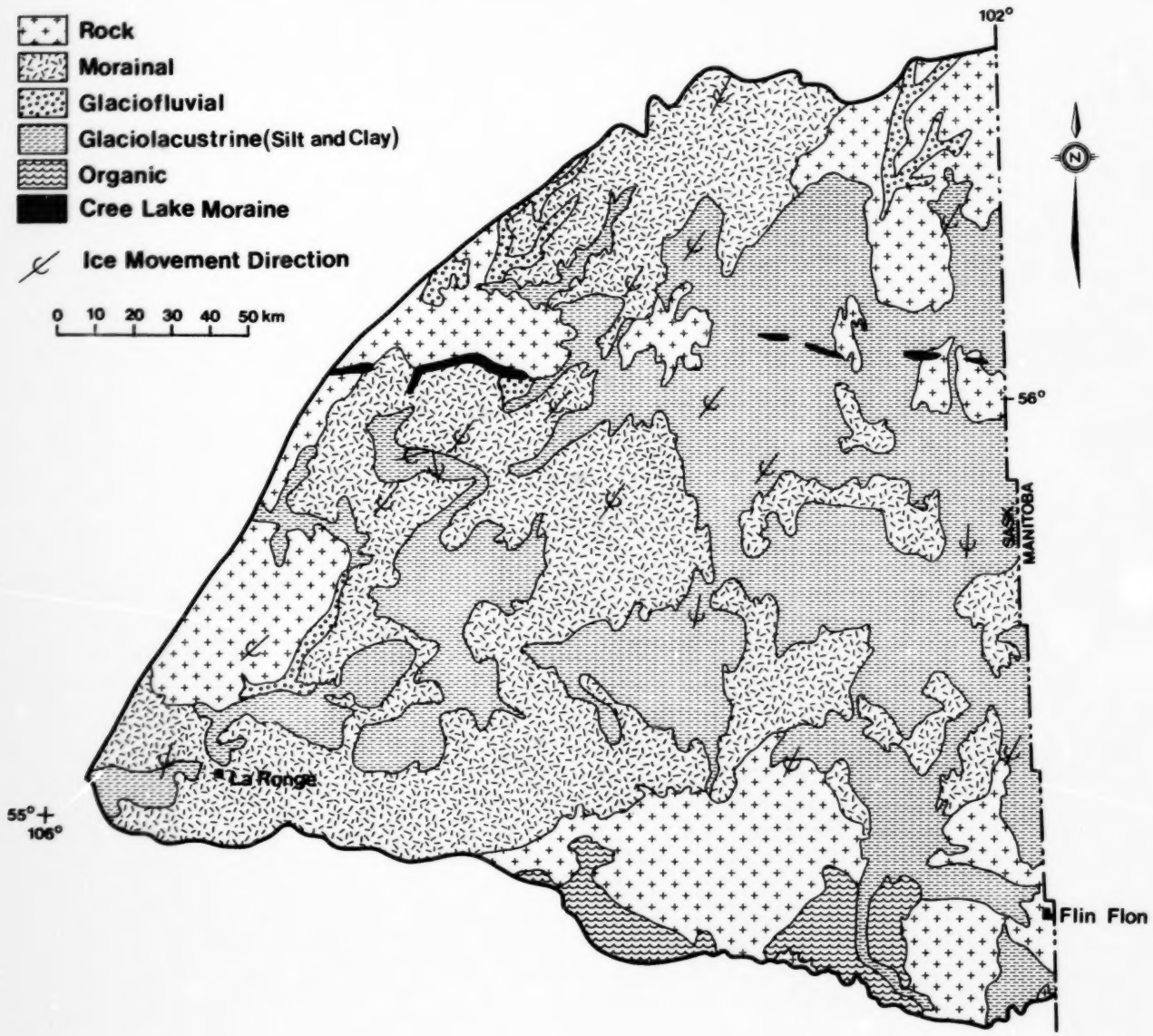


Figure 12. *Surface Quaternary geology for the southeastern Precambrian Shield. Only the dominant surface materials are shown.*

Glacial Landforms

In the area east of the La Ronge Domain the dominant glacial landform is thin ground moraine. This ground moraine is composed primarily of sandy ablation till.

The Cree Lake Moraine, a prominant and significant end moraine cuts the La Ronge Domain approximately 20 km south of Waddy Lake with segments extending east across the Kisseynew Domain (Fig. 12). This moraine can be traced for 800 km across the Shield east into Manitoba and northwest into Alberta. The moraine represents a major still-stand of ice in northern Saskatchewan (Prest, 1970), and is associated with regional features such as sandy outwash plains. As such, the Cree Lake moraine impedes surface geochemical exploration. However, its influence appears to be restricted to a 2 km wide belt at maximum.

The main glacial landforms which cover or have eroded bedrock and till, and are an impedence to geochemical surveys are eskers, ice walled channels, buried valleys, kettles and kames. In the area of interest, the combination of these deposits appears to comprise less than 5% of the total surface area.

Large quantities of ice contact stratified drift in a belt along Highway 102 north of La Ronge are thought to have been deposited by melt water flowing into Lake Agassiz through an ice walled channel (Schreiner and Alley, 1975).

Proglacial Landforms

The main proglacial influence was Lake Agassiz which covered a large portion of the map area. The area covered by the lake corresponds approximately to the area outlined by the extent of the glaciolacustrine deposits. Lacustrine material is also common in bogs and lakes, below the elevation of highest known beaches, within those areas mapped as dominantly moraine and bedrock.

Near Waddy Lake proper, lacustrine deposits commonly occur below 427 m elevation. This prediction results from information on beach elevations throughout the area particularly near Macoun Lake (Johnston, 1978). In the Waddy Lake area, lacustrine material was mapped up to 439 m elevation but commonly occurs below 427 m (Campbell, 1986). In at least one third of this area, surface exploration techniques will be affected by clay. Nearly all gold prospects found to date in the area are located above 427 m elevation.

The Byers fault system is a major structure which can be traced for at least 10 kilometres across the area (Byers, 1948). Gold prospects are located at several points along the structure. It is interesting to note that the northeast trending portion of the fault largely falls below the 27 m level while the east-west trending portion falls above the level and should be silt and clay free for the most part.

SURFICIAL SEDIMENTS

Glacial Sediments

The most common type of till is a sandy till as opposed to a very sandy till west of the La Ronge Domain. Silty till is common in areas underlain by volcanic rocks. "Clayey till" is the upper till unit. Although the clay fraction is not dominant it is much greater than in the other till types and therefore referred to as "clayey till" (Schreiner, 1984).

Sandy Till

Sandy till, the most common glacial sediment in the map area, occurs in various types of moraine and its component landforms. It is derived by glacial erosion of local bedrock and pre-existing glacial deposits.

Sandy till derived from basement rocks contains an abundance of large, angular, igneous and metamorphic boulders which commonly dominate the deposit (Fig. 13). Pebbles and cobbles are angular to subangular. The brown upper part of the till is oxidized, whereas the deeper part, grey in color, is unoxidized. The depth to which oxidation has affected the till varies, but in places it exceeds 5 m.

The grain-size of the sandy till varies considerably which is a common characteristic of till deposits (Goldthwait, 1971). Sand, the dominant component of the till matrix, ranges from 50 to 90 percent, whereas silt ranges from less than five to more than 40 percent and clay from less than 10 percent to negligible amounts (A, Table 1).

Composed of samples collected over Precambrian basement and within the Lake Agassiz basin

Texture	A Sandy Till			B Silty Till			C Clayey Till			D Sand & Gravel			E Silt			F Clay			G Colluvium		
	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples	Mean (wt. %)	σ (wt. %)	No. of Samples
SAND	71	10	141	45	9	23	39	17	75	82	17	110	15	14	108	5	5	112	23	12	5
SVC	12	7	141	6	4	23	7	5	73	13	19	102	2	5	30	1	1	8	5	3	4
SC	13	4	141	7	2	23	8	4	73	15	15	102	3	4	30	2	2	8	4	1	4
SM	11	4	141	6	2	23	6	3	73	13	12	102	3	2	30	2	1	8	3	1	4
SF	11	6	141	12	4	23	10	5	73	23	15	102	8	7	30	3	2	8	7	1	4
SVF	15	5	141	14	5	23	8	3	73	18	16	102	15	10	30	3	2	8	9	3	4
SILT	25	8	141	49	9	23	38	12	75	15	15	110	62	13	108	27	11	112	43	21	5
CLAY	4	2	141	6	2	23	23	12	75	3	4	110	23	14	108	68	13	112	34	30	5

Legend:

wt. %	= Weight Percent	SF	= Sand Fine (0.25 - 0.10 mm)
σ	= Standard Deviation	SVF	= Sand Very Fine (0.10 - 0.05 mm)
SAND	= Total Sand (2.0 - 0.05 mm)	SILT	= (0.05 - 0.002 mm)
SVC	= Sand Very Coarse (2.0 - 1.0 mm)	CLAY	= (<0.002 mm)
SC	= Sand Coarse (1.0 - 0.5 mm)	NA	= Not Available
SM	= Sand Medium (0.5 to 0.25 mm)		

Table 1. *Grain-size analysis for surficial sediment samples.*

Figure 14 shows the grain-size distribution in a typical sample of sandy till. The grain-size distribution in the sand fraction is commonly multimodal, with high contents of coarse and fine sand. Another mode exists in the silt range (Fig. 14).

The mineralogy of the fine fraction of the sandy till matrix, as indicated by X-ray diffraction (Fig. 15-A), reflects the bedrock source. Quartz, feldspar, amphibole and other minerals derived from igneous and metamorphic rocks dominate the graph. Chlorite, kaolinite, illite and possibly some other micaceous minerals are also present. Some are derived directly from the bedrock, while others are alteration products of minerals such as feldspars.

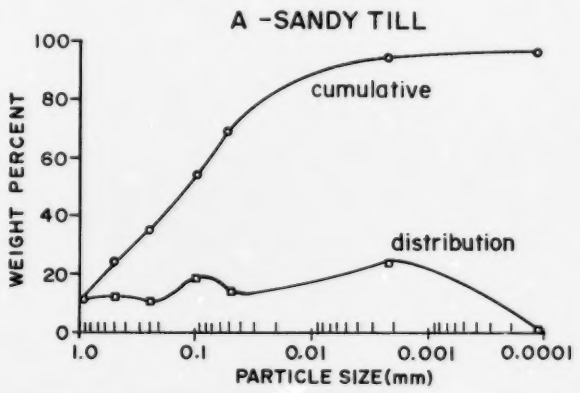


Figure 14. *Mean grain-size graphs for sandy till (from Table 1).*

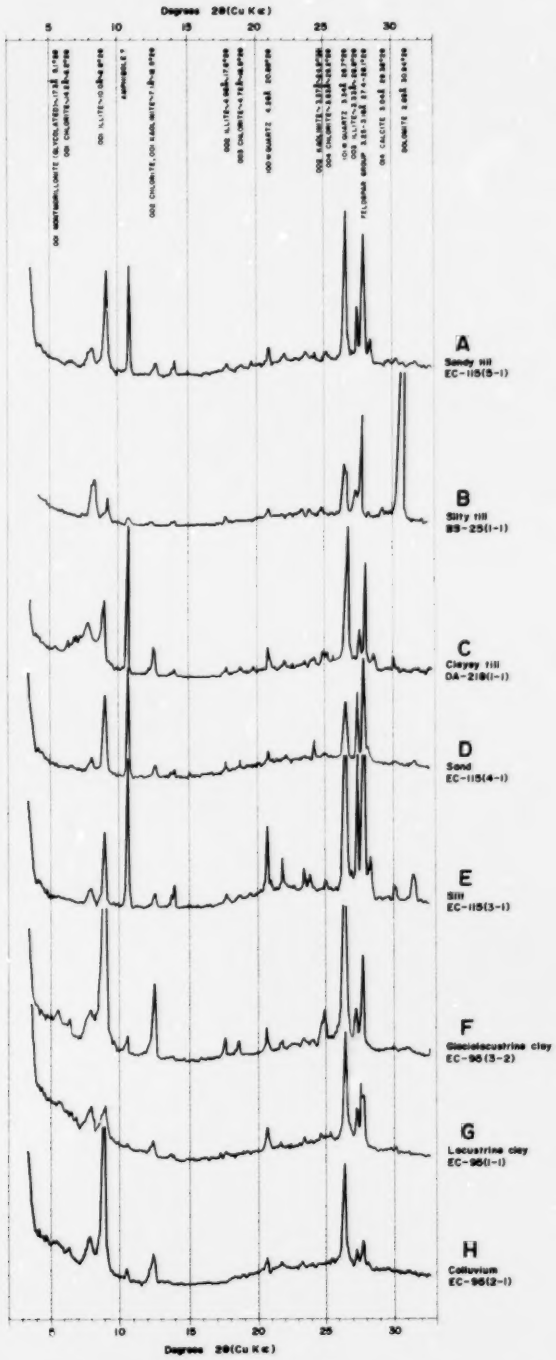


Figure 15. *X-ray diffractograms for each of the major surficial sediment types. Sample fraction 0.05 mm; all samples glycolated; Cu Kα radiation; 10³ cps; time constant 2; chart speed 1 cm/min; scanning 1° 20/min; 40 kv; 30 Ma.*

Silty Till

Silty till is scattered throughout the map area, but is most common in areas underlain by volcanic rocks. The colors are generally brown at the surface and grey at depth, but are darker than those of the sandy till. In contrast to sandy till, silt is the dominant matrix material, ranging as high as 65 percent and averaging about 50 percent (B, Table 1). Sand content ranges from less than 35 to more than 55 percent; clay normally makes up less than 10 percent of the matrix. The grain-size distribution in the sand fraction is bimodal, with minor modes in the coarse and fine sand (Fig. 16).

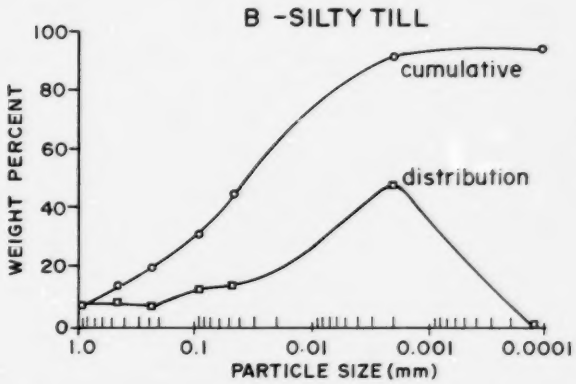


Figure 16. *Mean grain-sized graphs for silty till (from Table 1).*

In addition a major mode occurs in the silt range. The mineralogy of the silty till is similar to that of the more sandy, basement-derived till (Fig. 15-A,B).

Clayey Till

Till with a relatively high clay content occurs primarily in the southeastern part of the map area; it is mostly brown in color and contains pebbles and cobbles. The high proportion of clay and silt (C, Table 1) results in a material that is denser and more massive than either the sandy or silty till. The grain-size distribution in Figure 17 reveals a multimodal nature for the clayey till, with modes in the coarse and fine sand fractions, and occasionally in the silt fraction.

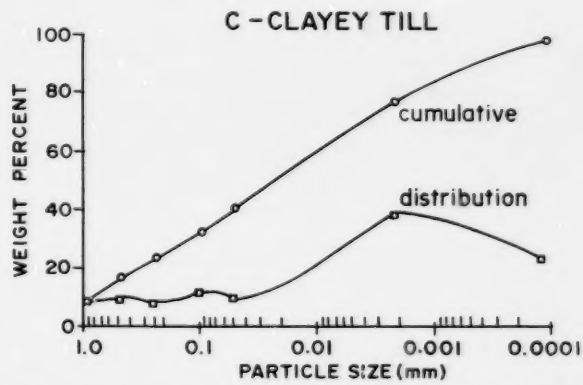


Figure 17. *Mean grain-size graphs for clayey till (from Table 1).*

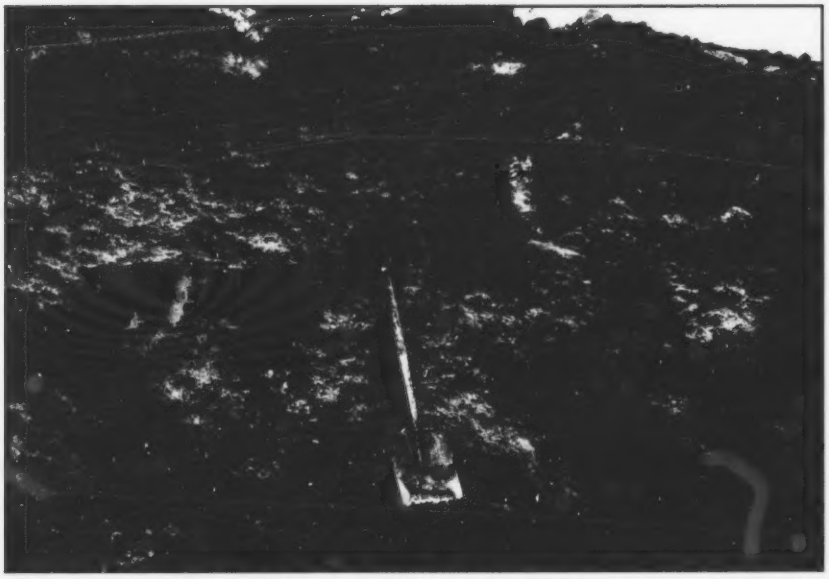


Figure 13. *Sandy till derived from Precambrian basement rocks showing abundant angular to subangular boulders.*

Figure 19. *Transgressive onlap (fining upward) sequence in Lake Agassiz sediments near Brabant Lake. Fine sand at the base is overlain by thick, sandy, varved silt. The varves are thin and contorted higher in the section and grade upward into massive silty clay.*

The mineralogy of the silt and clay fractions is similar to the other tills, with quartz, feldspar, amphibole and mica being very common (Fig. 15-A,B,C). The dominant clay minerals are chlorite, kaolinite, illite, and a minor amount of sodium montmorillonite. The montmorillonite is also found locally in the lacustrine sediments of the southeastern part of the area, which was inundated by Lake Agassiz The presence of montmorillonite in clay samples from the vicinity of Maguire Lake (NTS 63M-7) was also reported by Sopuck et al. (1977).

Montmorillonite is absent from the sandy and silty tills (Fig. 15-A,B). This indicates that Precambrian basement rock, the source of the tills, was not the source of the montmorillonite in the clayey till and lacustrine clay. The source of the montmorillonite is discussed in the section on "Glaciolacustrine Silt and Clay". The high clay content of the till and the presence of montmorillonite both suggest that the till was derived, at least in part, from the lacustrine sediments of the lake basin.

PROGLACIAL SEDIMENTS

Fluvial Sand and Gravel

These coarse sediments are the primary constituent of glaciofluvial landforms such as eskers, kames, kettles, crevasse fillings, outwash plains and ice-walled channels. The coarsest material generally comprises cobbles and pebbles, most of which are subangular to subrounded, indicating relatively short fluvial transport. Sorting is commonly moderate to poor. At depth, the sand and gravel is commonly grey to grey-brown. At surface, and extending to depths in excess of 10 m, oxidation has altered the color of these permeable sediments to yellow or yellowish brown. The base of the oxidized zone is interpreted to represent the lowest postglacial water table during the last glaciation.

Fluvial and Lacustrine Sands

Most stratified sands and beach sands represent shallow-water lake deposits. In the southeastern part of the area, sands commonly found at depth in augerholes are often masked by silt, clay or peat; these sediments were deposited at depth in Lake Agassiz.

The fluvial and lacustrine sands are normally medium to fine grained and well sorted. They are nearly white to pale yellow to grey or brown at depth in some augerholes. The very pale brown to yellow to yellowish-brown color of surface samples results from oxidation of the unsaturated sediments above the water table. The sand content of the samples is commonly about 80 percent in the southeastern part of the map area within the Lake Agassiz basin (D, Table 1). The mean grain-size distribution of samples collected in areas underlain by Precambrian basement rocks is bimodal in the sand fraction (Fig. 18).

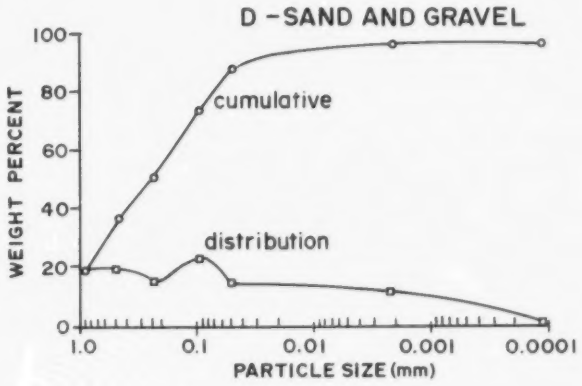


Figure 18. *Mean grain-size graphs for sand and gravel (from Table 1).*

This dominance of more than one grain size is not evident in individual samples, possibly because the mean distribution in Figure 18 is for a mixed population of sand and gravel and sand samples. This indicates that the modes in the sand and gravel sediments may be a reflection of the mineralogy of the source material, as was the case for the tills.

Glaciolacustrine Silt and Clay

Fine-grained sediments of glaciolacustrine origin are found primarily in the southeastern part of the map area, east of Highways 2 and 102 (Fig. 12). Silt and clay deposits also occur in the southern half of the Reindeer Lake basin (NTS 64D) and in the western half of the Lac La Ronge area (NTS 73P). Most were deposited in Lake Agassiz in the southeastern part of the map area. In fact, the distribution of silts and clays outlines the extent of this lake. Although many low areas are filled to a depth of over 10 m with fine lake sediments, bedrock is very common at the surface, especially at higher elevations. The glaciolacustrine deposits, therefore, form a discontinuous mantle interspersed with bedrock, lakes, muskeg, and other glacial and fluvial deposits.

Most glaciolacustrine sediments are massive, although varved silts were observed in some places (Fig. 19). At depth they are olive grey to dark grey in colour, while surface samples range from light grey to olive grey to brownish grey and greyish brown. Although color changes are not as marked as in the sands and gravels, they do indicate that weathering and oxidation have been surprisingly effective in these nearly impermeable sediments.

Table 1 gives the average composition of silt samples (E) and clay samples (F) from various parts of the area. The grain size distributions shown in Figures 20 and 21 are typical of the silts and clays respectively.

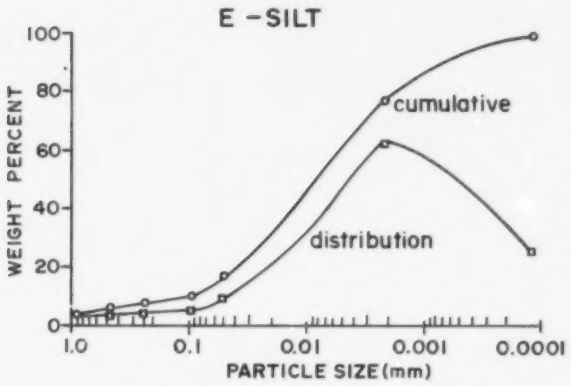


Figure 20. *Mean grain-size graphs for silt (from Table 1).*

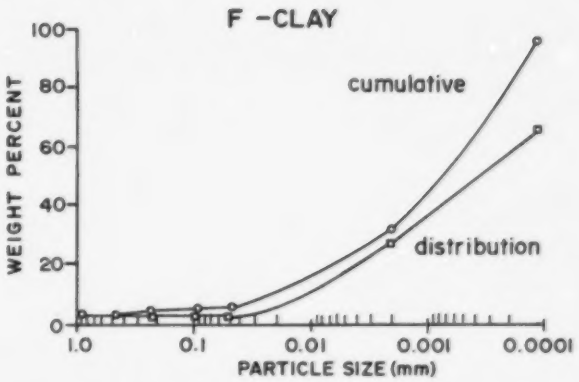


Figure 21. *Mean grain-size graphs for clay (from Table 1).*

Quartz, feldspar, and amphibole are the dominant minerals in both the silts and clays, and chlorite, kaolinite and micas (mainly illite) are the common clay minerals (Fig. 15-E,F). Schreiner and Alley (1975) reported finding montmorillonite in some samples of glaciolacustrine clay (Fig. 15-F). Montmorillonite is found in the Cretaceous rocks which outcrop south of the Shield in the Wapawekka Hills and other areas. It appears that the montmorillonite was carried in suspension by waters flowing into the glacial lake basin from areas of Cretaceous bedrock. Because the montmorillonite was derived from several scattered sources, it occurs only sporadically and in small amounts.

POSTGLACIAL SEDIMENTS

Colluvium

A few occurrences of colluvium were noted in the southeastern part of the map area. The grain-size distribution, with a high silt content and a sand value slightly greater than that of clay (G, Table 1), is similar to that of the lacustrine silt deposits and also resembles that of the silty till deposits (Fig. 16). Gravel and pebbles in the sediment distinguish it from a lacustrine deposit. The mineralogy of the fine fraction of the sediment (Fig. 15-H) is similar to that of other sediments with high silt and clay content, including the clayey tills. These similarities reflect the incorporation of lacustrine sediments in the matrix.

Lacustrine Silt and Clay

Lacustrine silt and clay are fine-grained sediments deposited in lakes during recent times. Lacustrine deposits, the most distinctive features of which is the presence of organic material, are common in the southeastern part of the map area where fine-grained sediments are abundant. Since many modern lake basins were previously occupied by glacial lakes, lacustrine silts and clays often overlie glaciolacustrine deposits (Fig. 22-A,B).

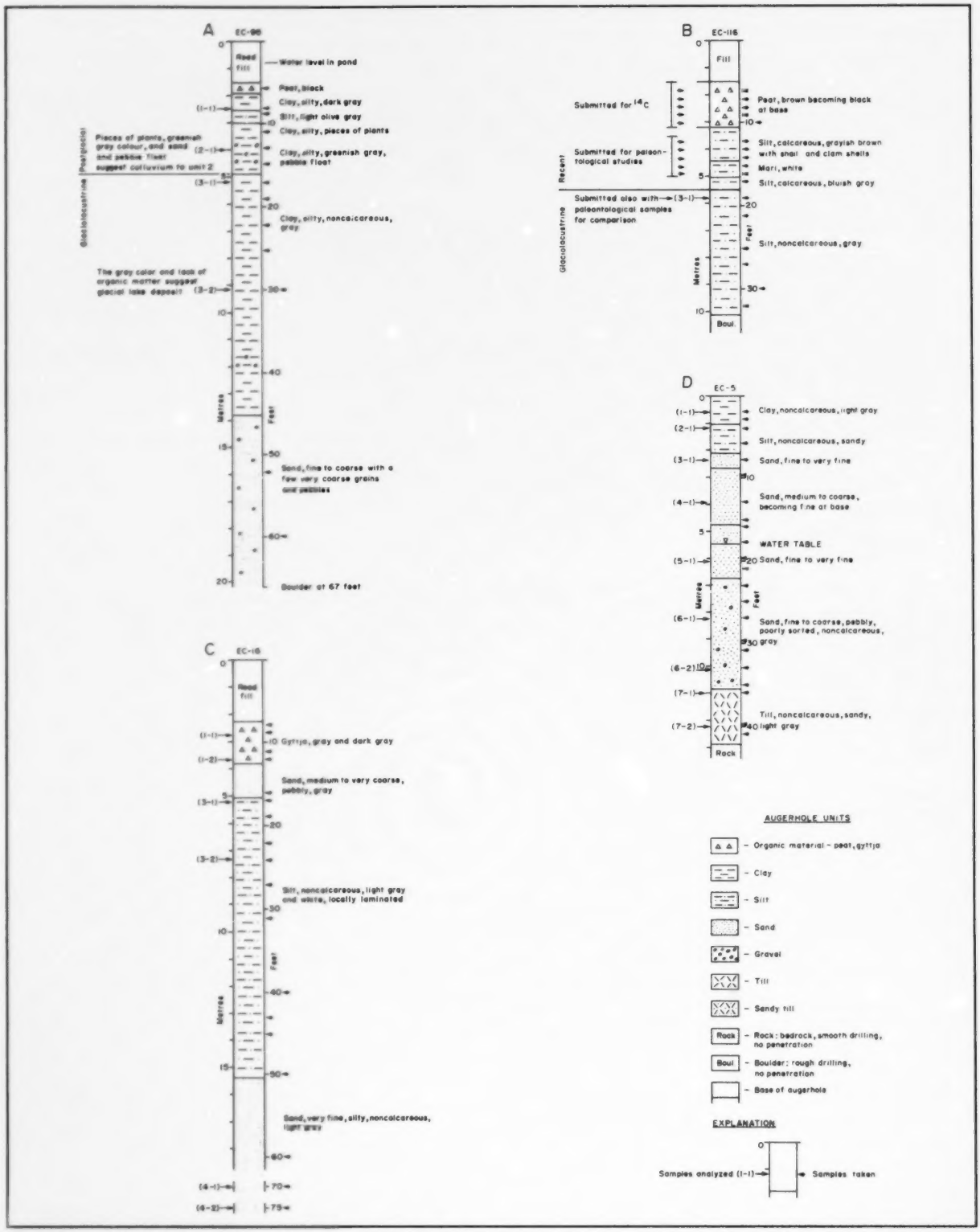


Figure 22. *Lithologic logs of lake sediments overlying till or bedrock. All show a general upward progression from glaciolacustrine sediments to recent lacustrine sediments and peat deposits.*

Recent lacustrine deposits resemble glaciolacustrine sediments in many respects. Grain-size distribution is similar, although modern deposits generally tend to be richer in clay, and varves predominate in glaciolacustrine sediments of high silt content. The mineralogy of the two materials is similar (Fig.15-F,G). The lacustrine silts and clays may contain plant remains, shells, marl and other organic debris (Fig. 22-A,B); the glaciolacustrine sediments are devoid of organic materials. Wilson (1981) also reports that samples of lake cores taken for palynological studies contain abundant pollen grains, where glacial lake deposits were barren.

Peat

Muskegs contain various kinds of peat accumulations. The peat occurring at surface is generally fibrous and brown, indicating that little decomposition has taken place. In most sections (Fig. 22-B), the material tends to become more decayed with depth, the end product being a well-decomposed black gyttja at the base of the bog. In some areas, the peat deposits are partially frozen.

DRIFT STRATIGRAPHY

Stratigraphic Framework

Roads in the area (Fig. 1) provided the means for investigating stratigraphic sections in exposures and borrow pits, and also provided access for a truck mounted power auger to sample and investigate drift units to a maximum depth of 35 m.

The generalized stratigraphy of the drift in the area comprises a lower till unit, an overlying stratified unit of glaciofluvial sands and gravels, and/or a glaciolacustrine silt and clay unit. An upper till unit and an upper stratified unit, occur at a few locations. This generalized stratigraphy was obtained from information in 53 auger holes along roads in the area, roadside exposures, excavations and overburden geochemical surveys. Location of two augerholes from areas where the upper till unit is present are shown in Figure 12 and the stratigraphy of these holes is shown in Figure 23.

The lower till was encountered in most of the 53 holes. Subdivision into two distinct units was made in only two holes and in excavations in the Stanley Mission area (E.A. Christiansen Consulting Ltd., 1977). The lower till in the auger holes has an average minimum thickness of only 1.75 m (range 0.5-15 m), which agrees with overburden surveys in the La Ronge and Flin Flon Domains. Thus the till is commonly thin in the region. No correlation of this lower till has been attempted over the study area due to the paucity of information and the extreme irregularity in relief.

The lower stratified glaciolacustrine sands and gravels related to ice recession are found in 12 of the 53 auger holes. On the surficial map, glaciofluvial material accounts for less than 5% of the surficial deposits.The high proportion of this material in the auger holes can be attributed to the fact that most of the holes were drilled along Highway 102 which follows deposits of stratified material.

Despite the fact that glaciofluvial material accounts for less than 5% of the surficial material, a thin patchy veneer of silty sand overlies till on a much broader scale. This veneer may only be a half metre thick or less, but it was the sampling medium for many B horizon soil surveys in this part of Saskatchewan. The seemingly ubiquitous veneer is likely the result of ablation and fluvial processes during ice recession and subsequent eolian activity.

Glaciolacustrine silts and clays are found in 41 of the 53 augerholes. Most of these sediments were deposited in glacial Lake Agassiz (Schreiner, 1983). This is a high proportion relative to their occurrence on the surficial map and may be related to the fact that drill holes were located in the areas of thicker drift and where buried subsurface deposits would likely be encountered. Average thickness of the sediments in the augerholes is 5.6 m (maximum 25 m). This unit represents the main deterrent to the success of surface geochemical surveys. Fortunately it is a relatively thin unit particularly in the western portion of the prospective area which coincides with the western limits of Lake Agassiz.

A thin upper till unit (< 2 m thick) related to a minor readvance of the ice is found over the glaciolacustrine silts and clays at a few locations. This till, found in only three of the 53 augerholes and at least two roadside exposures, is being recognized with greater frequency in surface geochemical surveys. It is expected that the upper till rarely contacts bedrock or lower till except where these units are exposed above the lower glaciofluvial and glaciolacustrine layers. As such the unit may be a tenuous sampling medium in many areas. Generally, the upper till can be distinguished from the lower till by higher silt and clay contents. The silt and clay are derived from the underlying glaciolacustrine material.

In the augerholes the upper stratified unit is distinguishable above the upper till unit. Where the upper stratified unit occurs over lower stratified sediments it is not possible to separate these two units. The

glaciolacustrine sediments commonly show a fining upward sequence with sands at the base grading to silt and clay indicating a retreating source of sediment (ice recession). In a few cases this sequence is reversed in the upper part of the section suggesting a readvance of the ice into the lake basin which likely coincides with the deposition of the upper till.

Glacial Stratigraphy

Sections of glacial till, ranging in thickness from less than 0.5 m to more than 10 m, from various parts of the map area are summarized in this section to provide examples of typical stratigraphic settings.

Stanley Mission

During a geological investigation of the Quaternary deposits in the Stanley Mission area, (Fig. 1) two tills overlain by lacustrine silt and clay were encountered in test trenches (E.A. Christiansen Consulting Ltd., 1977). The lower, harder till is composed of grey unoxidized and greyish-brown oxidized sandy till. The upper, softer till is composed of grey unoxidized and olive-brown oxidized sandy and bouldery till. Both tills are devoid of expandable clay minerals. The presence of unoxidized till in the basal portion of the upper unit suggests that oxidation took place in the upper part of the lower unit prior to deposition of the upper till. Thus, these two units were likely deposited during separate glaciations and the oxidation of the lower till represents a weathering interval.

Otter Rapids

A number of exposures revealing multiple till sections are found north and south of Otter Rapids, which is where Highway 102 crosses the Churchill River (Fig. 1). In one section located about 6.5 km north of Otter Rapids, a hard, fractured, jointed, silty sand till is overlain by a clay-rich cobbly till. The contact between these units is distinct and represents an erosional surface. The lower unit is more consolidated and is stained along joint fractures, indicating that it underwent weathering prior to deposition of the upper till.

Similarly, an exposure about 1.5 km north of Otter Rapids reveals two till units separated by an oxidation zone which contains balls or lumps of the lower till. As in the case of the Stanley Mission section, a period of weathering separated the glaciations responsible for the two till units.

Deschambault Lake

Several stratigraphic sections, particularly in the southeastern part of the study area, show a layer of till overlying fluvial or lacustrine sediments. A section near Deschambault Lake which exhibits this sequence (Fig. 23-A) consists of (from bottom to top): 1 m of sandy till; 1.5 m of sand which grades from pebbly at the base to medium grained at the top; less than 0.5 m of silt; and 2 m of till, which can be divided into a lower, light olive-grey, noncalcareous till composed of 63 percent sand, 30 percent silt and 7 percent clay, and an upper light grey till composed of 74 percent sand, 25 percent silt and 1 percent clay. The bimodal nature of the sand fraction confirms that the deposit is till. The lower and upper parts are believed to be lodgement and ablation till respectively.

Jaysmith Lake

A 5 m deep augerhole near Jaysmith Lake (Fig. 23-B) revealed the following sequence (from bottom to top): 0.4 m of sandy till; 3.3 m of lacustrine sediments which grade upwards from clayey silt through silty clay to clay; and 1.0 m of silty, clayey till which contains more than 50 percent clay. The lacustrine sediments and the upper till both contain montmorillonite, the origin of which was discussed in the section on "Glaciolacustrine Silt and Clay". The high content of silt and clay in the till and the presence of montmorillonite and some carbonaceous material suggest that the till has incorporated some of the underlying lacustrine deposits. A similar clay-rich till (see "Clayey Till" section), which occurs sporadically on surface throughout the Lake Agassiz basin, indicates that the ice readvanced into the basin after the lacustrine sediments were laid down.

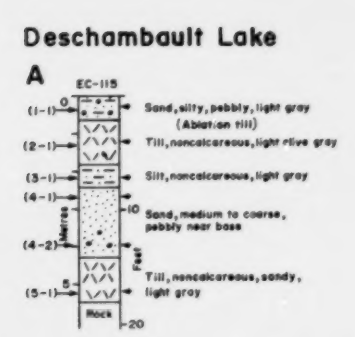
Mirond Lake

An exposure on Highway 135 south of Pelican Narrows shows approximately 1 m of sandy till overlying stratified sand and gravel. A distinct contact separates the two units (Fig. 23-C).

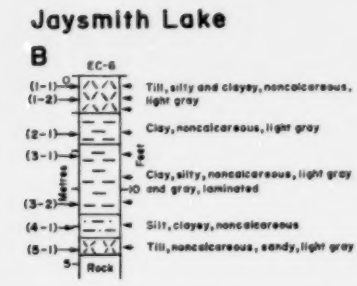
Missinipe

An exposure in a gravel pit on Highway 2 about 10 km south of Missinipe (Fig. 1) shows a thick section of stratified gravel and sand which grades upward into silt. This material is overlain by about 1 m of till, with the lower part rich in silt and clay and containing large boulders, and with the upper part being more sandy and loosely packed. This unit may comprise both lodgement and ablation till. The contact between the till and the underlying silt is very distinct (Fig. 23-D).

The sections at Deschambault Lake, Mirond Lake and Missinipe reveal that a glacial cycle was followed by a period of retreat during which fluvial gravel, sand and silt were deposited. The ice then readvanced and covered these sediments with a layer of till.

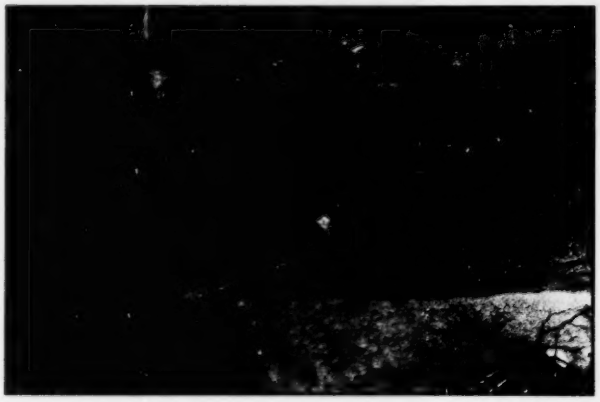


A. *Lithologic log from augerhole at Deschambault Lake.*



B. *Lithologic log from augerhole at Jaysmith Lake.*

C. *Thin till overlying gravel on Hwy. 135 north of Pelican Narrows near Mirond Lake.*



D. *Thin till overlying stratified silt and gravel on Hwy. 2 about 10 km. south of Missinipe.*

Figure 23. *Lithologic logs and exposures of till overlying lacustrine and fluvial sediments which are underlain by an older till deposit. Approximate locations are shown on Figure 1.*

Rabbit Creek

A composite section of two augerholes drilled at Rabbit Creek, about 25 km south of La Ronge on Highway 2, also indicates a readvance of ice over Lake Agassiz sediments. The section, from bottom to top, is as follows: greater than 20 m of dark grey, hard silt which contains layers of till less than 1 m thick; nearly 7 m of brown sandy silt till; 2 m of calcareous, soft, brown silt; about 1 m of soft, brown, oxidized, silty till; slightly less than 3 m of clay grading upward into silt and fine sand.

The thick lower silt unit was likely deposited during a high-level phase of Lake Agassiz. The thick overlying till must have been deposited by a readvance of ice which incorporated some of the silt into the till. The clay, silt and sand sequence at the top of the section was deposited in Lake Agassiz after the ice had receded from this area. Other sections in this vicinity also suggest that readvance of ice and the presence of Lake Agassiz before and after the readvance. However, all of these sections require more detailed investigation and correlation in order to accurately determine the true sequence of events.

Proglacial Stratigraphy

Ice-contact deposits are exposed along the roads in the eastern half of the area, especially along Highway 2 and 102 from La Ronge to McLennan Lake and along Highway 135 north and south of Pelican Narrows. Many of the occurrences examined show a complex relationship of different sediments. An exposure north of McLennan Lake reveals layers of sandy till intermixed with beds, lenses and pockets of sand, silt and stratified sand and gravel. A borrow pit east of Highway 2 on the road to Stanley Mission exposes a sorted and stratified gravel overlain by a sequence of stratified sand and silt and a thin layer of sandy gravelly till. A large block of hard, grey, massive till within the gravel is underlain by gravel and fine sand. An exposure along Highway 135 consists of dirty gravel overlying a silt layer which contains lenses or blocks of clay. The variable nature of the stratigraphy in these deposits suggests an environment, such as an interlobate area or eskerine kame complex, where sediments were deposited in contact with an ablating ice margin.

An outstanding characteristic of the proglacial drift within the Lake Agassiz basin is a 'fining upward' tendancy in the sequence of sediments. The typical sequence, as shown in Figure 22-D, consists of till deposited on bedrock and overlain by coarse gravel grading upward to sand. Silt covers the sand, and clay comprises the uppermost part of the section. A similar sequence occurs in a section of Lake Agassiz sediments near Brabant Lake (Fig. 19). Fine sand is overlain by varved silt, the varves being thick and flat lying at depth but thinning toward the surface and becoming contorted. The silt grades upward into an amorphous clay deposit.

The 'fining upward' sequence of sediments resembles the transgressive onlap sequence produced by the advance of a water body across a land surface. As meltwater discharged from the receding ice front, it carried debris into the ice-dammed Lake Agassiz. Coarse material was deposited in the area near the ice front; finer sediments were carried farther out into the lake. As the ice front receded, finer sediments were continually being deposited over coarser material.

Postglacial Stratigraphy

Modern lacustrine silt and clay deposits occur in some parts of the area, mainly in the Lake Agassiz basin; they commonly overlie glaciolacustrine sediments. This type of sequence, in which 2 to 3 m of recent sediments overlie glacial lake deposits, is shown in Figures 22-A and B. In 22-A, the lower part of the recent material may be a clay-rich colluvial deposit, whereas the upper part is clay. In 22-B, the recent sediments consist of grey silt with some marl and other organic material.

Peat, generally 1 to 2 m in thickness, forms the top of many sections (Fig. 22-A, B, C). Several holes drilled through road beds into peat bogs to obtain samples for radiocarbon age dating, revealed that, on average, the peat deposits were compressed to one-third of their original thickness by the weight of the road fill. Results of the radiocarbon dating are given in Table 2.

Stratigraphic Correlation

Stratigraphic correlation of drift units in the Precambrian Shield is difficult. The rugged terrain, a reflection of bedrock relief, provides many basins where drift units may accumulate and provide a nearly continuous record of events, whereas many hills are stripped bare, exposing bedrock. These uplands commonly separate the lower lying areas and prevent direct correlation of drift units over large areas.

Correlation of till units using diagnostic parameters is also difficult on the Shield. The Precambrian basement rocks vary greatly in lithology over short distances, commonly hundreds of metres. The glacial till, composed of comminuted bedrock and reworked material from earlier drift units, therefore, also varies in composition over short distances.

Correlation of till units may be possible on a local scale. For example, two sections north of Otter Rapids can be correlated to a certain extent. The lower till units in both sections are hard and compact, and have similar

grain sizes and degree of oxidation. These two units can therefore be correlated on lithologic parameters in the same manner as rock stratigraphic units.

Colour changes, heavy mineral assemblage and other characteristics may sometimes be used to correlate units over short distances. For stratigraphic correlation, numerous testholes are required and detailed analysis of samples is essential. Such work may permit correlation of drift units over small areas, such as within a mining property.

Stratigraphic Interpretation

Although correlation in many places is complicated or impossible, the stratigraphic sections examined reveal a great deal about the sequence of events and types of processes that occurred in the area. Multiple till sections in which the lower till units are oxidized indicate that more than one glaciation has occurred and that these glacial advances were separated by intervals of weathering, suggesting relatively long periods of ice-free conditions.

The truncated contacts between tills and the incorporation of lumps or 'balls' of lower till into the upper unit also suggest successive ice advances. A lodgement-ablation sequence is suggested when the lower part of a till is consolidated and the upper part is loose and more sandy. Tills with differing lithologies indicate different source materials and imply either a change in ice-flow direction from one glacial advance to the next or glacial stripping of bedrock between glaciations. glaciations.

The intertill deposits reveal that glacial deposition of till was followed by fluvial deposition of gravel and sand as the ice melted. These sediments were in turn covered by glacial till, probably deposited by a readvance. The upper till which occurs in a number of these sections is consistently thin, only about 1 m thick, and ranges from sandy to silty to clay-rich. The matrix seems to correspond to the underlying sediments in most places. The lower contact of the unit is generally distinct. The clay-rich upper till is widely distributed, primarily within the Lake Agassiz basin, suggesting that it is the result of a readvance into the basin. The extent and relationships of this readvance were discussed by Schreiner and Alley (1975). The advancing ice presumably eroded the pre-existing sediments, resulting in truncation of the drift units. The ice which overrode the fluvial or lacustrine sand, silt and clay incorporated these sediments into the upper till. The till matrix, therefore, commonly resembles the underlying sediments and is separated from them by a distinct contact.

Generally, the higher the clay content of the till, the fewer clasts it contains and the more it resembles a lacustrine deposit. Such tills may be waterlaid (Dreimanis, 1976), having been let down from beneath a floating ice mass. Ice in the Lake Agassiz basin is therefore believed to have been partly afloat, giving rise to the deposition of the clay-rich tills.

Langford (1975, 1977) explained the clay-rich till and other till-like deposits observed in exposures and drillholes along the Churchill and Reindeer River valleys as flow or slump deposits. The ice-contact deposits and outwash along Highways 135 near Pelican Narrows, which were also noted by Langford (1975) and Shawinigan Engineering Company Limited (1973), are likely to contain this variable stratigraphic sequence, with tills and intertill deposits intermixed. This zone is probably an interlobate area and may extend farther north along the Churchill River toward the Reindeer River valley (Fig. 1). Many of the till-like deposits and the complicated stratigraphy may have resulted from the deposition of ice-contact deposits in this interlobate zone. Some of the more recent material could be the result of mud flows or slumps, as suggested by Langford (1977).

The author, however, maintains that the uppermost diamictic unit, which in many sections overlies stratified or lacustrine sediments, is a till. If this is the case, the tills, whether or not they are flow tills, must have been deposited during a readvance which covered a wide area because they overlie drift deposits in an extensive area.

The 'fining upward' sequence of lake sediments suggests a retreating ice mass that supplied sediment to the Lake Agassiz basin. The lake transgressed across the land, following the retreating ice. This process of lacustrine sediments filling the basin as the ice receded occurred in a number of other cases. Peat accumulated in shallow depressions as muskeg. In the drier regions, particularly the western half of the study area, strong winds were actively reworking sand into dunes, and loess was laid down as a blanket covering pre-existing deposits.

QUATERNARY HISTORY

Introduction

Continental glaciers advanced and retreated across the study area during the last two to three million years of the earth's history. Although multiple tills occur, the paucity of stratigraphic information prevents an interpretation of glaciations earlier than the last or Wisconsinan glaciation which is recorded and shown in sketches (Figs. 24 to 27).

The criteria on which the history of deglaciation is based include glacial deposits, landforms, drainage, stratigraphy, and radiocarbon dates. The deposits and landforms indicate the environments; the drainage, stratigraphy, and radiocardon dates provide methods of correlating these environments.

The phases of deglaciation merely portray a chronologic sequence of events. Whether the ice frontal positions shown represent an active or stagnant ice margin is generally not known. Landforms, such as end moraines that define an ice margin, such as the Cree Lake Moraine are not common. Therefore, most ice positions shown coincide with a particular glacial drainage pattern.

Phase 1 - Deglaciation History

Phase 1 of the deglaciation history of the study area (Fig. 24) corresponds to Phase 8 of the deglaciation history of southern Saskatchewan and adjacent areas as described by Christiansen (1979).

The large body of water which occupies the southeastern part of the area is a northern extension of Lake Agassiz. Beaches along the Wapawekka Hills, reported by Langford (1973), as well as along the Pasquia Hills and other uplands of the Manitoba Escarpment are strandlines of glacial Lake Agassiz formed during Phase 1, which corresponds to the Campbell Level of Lake Agassiz (Elson, 1967) and to the Emerson Phase of Fenton et al. (1983). The glacier front stood in the position as shown about 10,000 years ago.

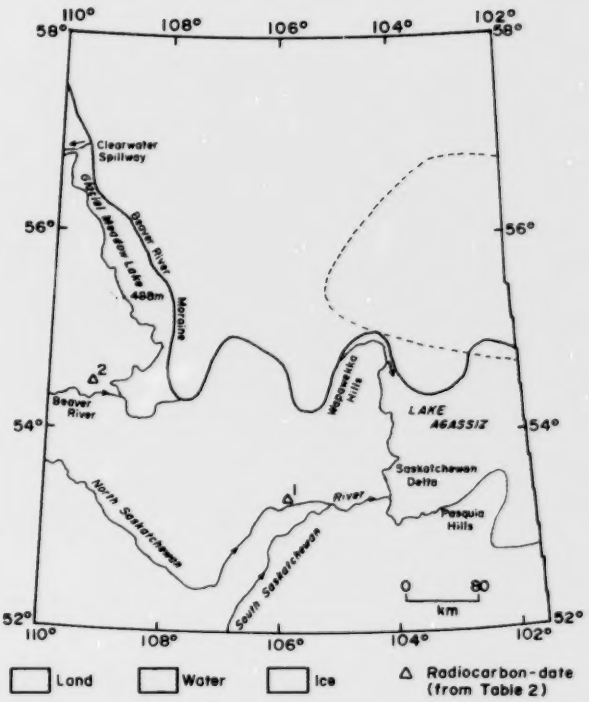


Figure 24. *Phase 1 of the history of deglaciation about 10,000 years ago.*

Phase 2 - Deglaciation History

In the eastern part of the area an upland protruded as a nunatak through the thinning ice mass (Fig. 25). Its position is marked by a moraine. The model of deglaciation developed by Christiansen (1956) to explain the origin of the ice-disintegration features covering Moose Mountain was employed to explain the origin of this nanatuk which initiated the development of an interlobate area.

Beaches described by W.G.Q. Johnston (1978) near Macoun Lake, at an elevation close to 457 m, are thought to have developed in the northern part of the interlobate area where water was ponded between the ice mass and the topographically high land. Highways 2 and 102 follow this interlobate zone from La Ronge to north of Missinipe. Ice-contact deposits, typical of this very actively ablating interlobate area, are exposed along the road. A large quantity of water from the melting ice flowed south to Lake Agassiz. Stratified sands and gravels, such as those south of Missinipe, were deposited by meltwater. Farther south, stratified sands were deposited. A delta of fine sand was formed where water discharged into Lake Agassiz. Ice-contact deposits north and south of Pelican Narrows along Highway 135 also indicate rapid melting of the

glacier. They are believed to have been associated with another interlobate zone.

As previously discussed, several indications of a minor readvance were discovered within the lake basin of the study area. It is postulated that the readvance occurred after the ice had retreated to a position farther north. The ice then expanded to some point in the lake basin which may have been similar to that shown in Phase 2 (Fig. 25).

Phase 3 - Deglaciation History

As the ice retreated, Lake Agassiz again invaded the lowland area. The retreat of the ice and the transgression of the lake water is recorded in a sequence of beds, similar to a transgressive onlap sequence, which results in the lake sediments becoming coarser with increasing depth in a section.

According to Elson (1967) a stage of the Campbell Level of Lake Agassiz extended to the northwest and drained through the Clearwater River. However, no evidence of beaches or lake sediments was found west of the position of Lake Agassiz as shown in Figure 26.

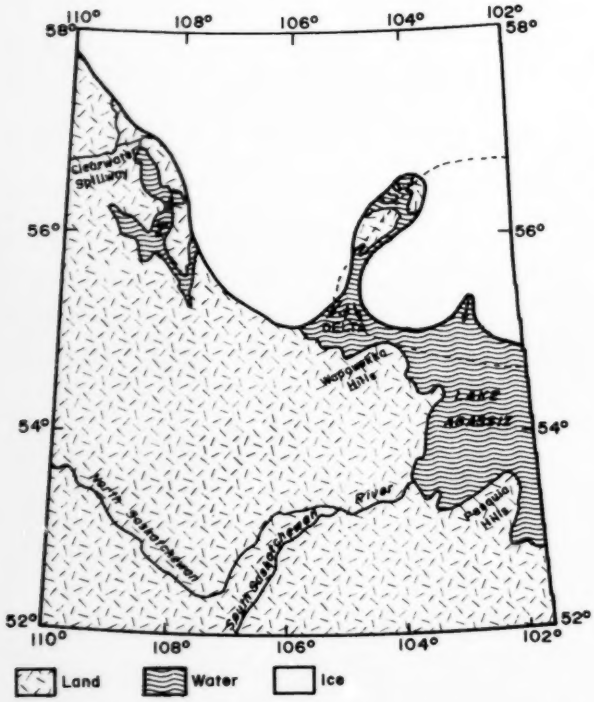


Figure 25. *Phase 2 of the history of deglaciation about 9,700 years ago.*

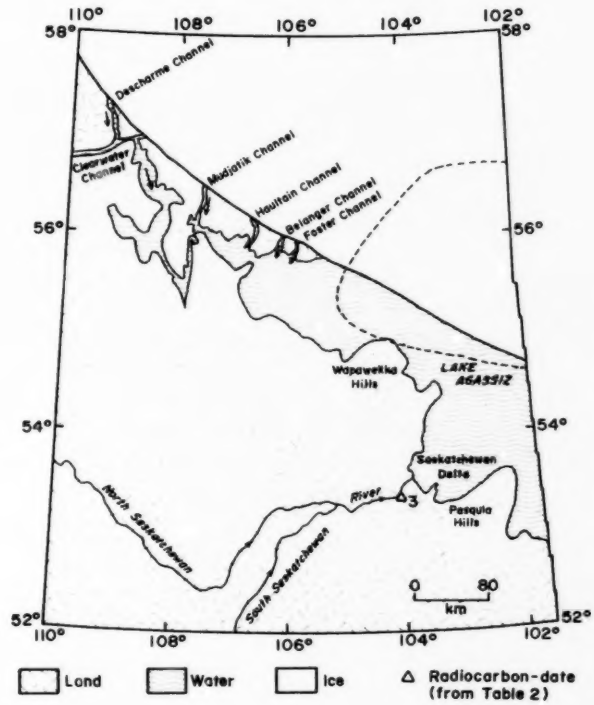


Figure 26. *Phase 3 of the history of deglaciation about 9,500 years ago.*

It appeared that Lake Agassiz was lowered to this level before the ice retreated, and, consequently, the lake could not drain through the Clearwater River at this time. A series of meltwater channels carried water south to Lake Agassiz, which then occupied the area surrounding what is now the Churchill River. The most notable of these channels were those of the Haultain and Mudjatik Rivers, which deposited prograding deltas where these channels entered Lake Agassiz. The ice position was located as shown about 9,500 years ago.

Phase 4 - Deglaciation History

During Phase 4, the ice margin is shown at the Cree Lake Moraine (Fig. 27). The moraine represents a terminus of a glacial readvance or remobilization as indicated by Prest (1970, Figure XII-15). Strandlines were cut into the south side of the Cree Lake Moraine at about 405 m, with the highest wave cut terrace at about 420 m. The extent of the lake deposits and the beaches indicates that the lake extended farther north (Fig. 27) than portrayed by Elson (1967).

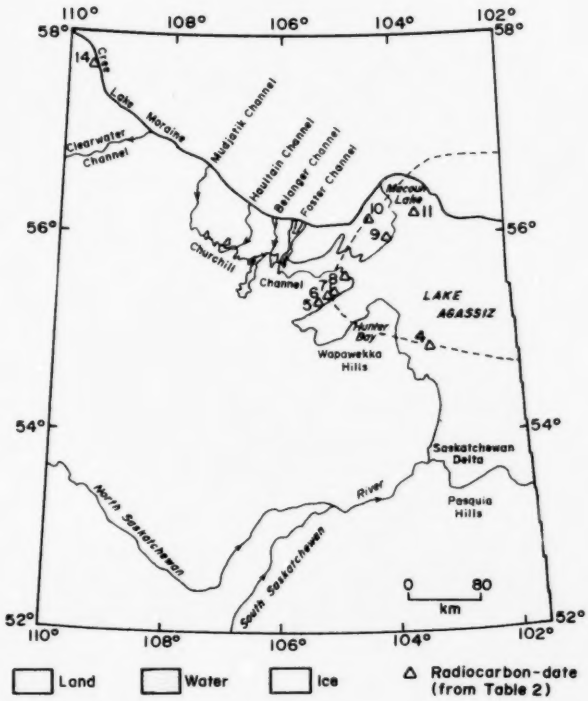


Figure 27. *Phase 4 of the history of deglaciation about 9,000 years ago.*

Several beaches farther south, as well as those reported by W G.Q. Johnston (1978), indicate a significant level near 396 m. The presence of lake clays and silts to an elevation of 396 m north of Pelican Narrows suggests that the lake existed at about 400 m. A wave-cut strandline at Hunter Bay on Lac La Ronge is at elevation 380 m. The elevation of some beaches along the Wapawekka Hills corresponds with this level. Some of these beaches and lake sediments are related to other successively lower lake levels of Lake Agassiz, which followed the second Campbell Phase as explained by Elson (1967, p. 93). Radiocarbon dates reveal that the land in this area was free of ice at least 8,000 years ago (Table 2, #10).

Site No.	Site Name	Location	Sample	Material	Years B.P.	Comments
1	Prince Albert	53°14'N 105°44'W	GSC-648	organic sand	11 560 ± 640	base of pond deposit, 600-620 cm below bottom of pond
2	Waterhen River	54°27'N 109°12'W	S-964	marly silt	9935 ± 170	10 m deep at base of marly silt, with wood and shells
3	Nipawin	53°18'N 104°04'W	S-2166	carbonaceous, sandy silt	10 265 ± 585	10 m deep at base of eolian sand covering fluviolacustrine sediments
4	Deschambault	54°55'N 103°23'W	S-1065	peat	5900 ± 80	base of peat overlying recent and glaciolacustrine silt
5	Cycloid Lake (A)	55°15'N 105°16'W	GSC-643	basal gyttja	8520 ± 170	gyttja overlies organic brown clay and inorganic clay
6	Lake A	55°20'N 105°03'W	S-1504	organic clay	8055 ± 155	depth 350 cm in pond deposits
7	Naniskak Lake	55°26'N 104°56'W	S-1502	organic clay	7680 ± 90	depth 450 cm in pond deposits
8	Wheeler Creek	55°35'N 104°47'W	S-949	gyttja	7305 ± 95	base of gyttja overlying sand and silt
9	South of Cree Lake Moraine	55°53'20"N 104°04'30"W	GSC-1446	gyttja	8640 ± 240	gyttja overlying silt clay over coarse bouldery gravel
10	North of Cree Lake Moraine	56°07'30"N 104°24'20"W	GSC-1466	organic silt	8230 ± 250	depth 562-572 cm in pond deposits
11	Junction Hwys. 102 and 105	56°15'N 103°35'W	S-1231	peat	6420 ± 115	in palsa, 2 m deep above silt

Table 2. *Significant radiocarbon dates.*

DRIFT PROSPECTING — POTENTIAL, PROCEDURES, AND PROBLEMS

The purpose of this section is to more specifically deal with aspects of drift prospecting such as geochemical analyses, gold grain studies, dispersion trains, and the methodology for effective drift prospecting. Problems that may be encountered by the explorationist are identified along with recommendations to avoid such difficulties and employ techniques to prospect successfully using drift deposits. This interpretation is based on existing data and is analysed taking into account the regional setting as presented in the first part of this review.

A number of investigations related to drift prospecting have been carried out in the study area in particular in the La Ronge Domain. Over the years work has been done involving geochemical prospecting using soils, lake sediments, and vegetation as well as subsurface sampling of tills using portable drilling equipment.

The area was covered by the GSC-SGS geochemical lake sediment survey (Hornbrook et al., 1975; and Hornbrook and Garrett, 1976). Sopuck et al. (1980) worked with the data from these studies and related the geochemical anomalies to the bedrock lithostructural domains and determined that there was a strong dependency on the Quaternary geology conditions. Numerous other more site specific investigations have been conducted reflecting different aspects of drift prospecting.

Within the last few years new studies have concentrated on gold in till deposits and the associated aspects as the prime prospecting method. Regional surveys involved sampling tills from portions of the La Ronge, Glennie Lake and Flin Flon Domains. More detailed gold in till orientation surveys were carried out over the Star Lake (21 and Rush Lake zones) and the Tower Lake properties. These investigations have been reported on by Sopuck et al. (1986).

The Waddy Lake area was studied in considerable detail by Campbell (1986). This area contains numerous gold showings and prospects such as the Komis, Kosta, Weedy Lake and Wedge Lake deposits and includes the EP Zone a gold deposit located by subsurface drift prospecting with its associated mineralized till the "Riddle Till".

These latter studies are the most detailed and current and incorporate much of the older information and since they concentrate on prospecting for gold they have been chosen as the key information sources for this present review.

These investigations involved establishing the regional Quaternary geology setting, but then concentrated on the gold in till deposits as the method for prospecting. The gold was analysed for geochemically and by heavy mineral separation in various till fractions following techniques developed by Overburden Management Ltd. and SRC. The techniques involved will not be elaborated here; however, the results of these studies will form the bases of information which is applied to the remainder of the area.

GEOCHEMISTRY

Alteration lithogeochemical studies were carried out by Sopuck et al. (1986) to evaluate the nature of any wallrock alteration or mineralization characteristics which may be of use in a till survey. Forty samples from each of two holes through both the 21 Zone, Rush Lake, and Tower Lake mineralization were analyzed for a variety of major, minor, and trace elements.

No significant mineralogical or geochemical halos exist in wall rock more than 1-2 m from mineralization. Alteration within the granitic rocks adjacent to mineralization consists mainly of minor sericitization of feldspars, hematization and epidotization. Carbonate alteration is generally lacking.

Gold content in wall rock is less than 2 ppb only 2 m from high grade intersections while a few of the samples contained elevated levels of Cu, W, As, and Te. Chalcopyrite and arsenopyrite have been rarely noted in association with the higher grade intersections.

At Tower Lake the main mineralogical alteration is hemitization and limonitization after pyrite. Gold contents are elevated in all samples over the length of the hole along with Mo, W, and F which are associated with mineralized intersections.

Gold in the Waddy Lake area is not related to any specific rock type. Gold is present in, and adjacent to, quartz veins, which occur in both intrusive and extrusive rocks (Coombe, 1984; Harper, 1984). Coincidently, there is little relationship between pebble lithology of a till sample and its gold value. Higher copper values are associated with samples dominated by intermediate-to-mafic volcanic clasts.

The Komis and Kosta deposits are broad masses of silicified and pyritized andesite, in which gold occurs in quartz veins and veinlets, in quartz filled fractures, and in granitic dikes and dikelets. The host andesite carries from 1% to 5% pyrite, in disseminated cubic form (Kidd, 1979).

The drift sediments associated with both deposits contains very high levels of gold with the levels being 2-5 times higher for the Kosta deposit. The Riddle-Kosta

till contains a complex suite of associated minerals which included native copper, galena, and sooty chalcocite-galena plus traces of pyromorphite, bornite, molybdenite and a goldsilver alloy. These minerals were readily destroyed by postglacial surface oxidation and therefore are not present in near surface samples. Samples from near the Ep Zone deposit yield up to 10,000 gold particles most of which are delicate in shape.

Based on the present mineralogical-lithogeochemical studies, gold itself appears to be the best pathfinder to mineralized zones in terms of drift prospecting.

NATURE OF GOLD IN DEPOSITS AND RELATED TILL

Gold at the 21 Zone is typically fine grained, generally 50 microns (μm) in size although particles up to 250 μm are present. Examination of polished sections indicates that gold occurs along quartz grain boundaries and also as isolated grains in pyrite. Shearing results in the redistribution of gold in fractures in the pyrite and quartz.

At the Rush Lake zone, the main mineralization is quartz vein related; however, the nature of the gold is not well known. The Tower Lake prospect lies along an east-west fault zone. Gold occurs as 30-60 μm grains with limonite in the high grade intersections. Highly fractured, limonitic volcanic and intrusive rocks host the mineralization. In the Waddy Lake area the gold is also quartz vein related and tends to be fine-grained in nature.

Considering the characteristic fine size of gold grains, shape classification may be tenuous under the binocular microscope; however, the observed trends appear to indicate distance travelled in many cases. Shape classification of gold grains as delicate, irregular, abraded or rounded and associated travel distances is according to the method established by S. Averill, Overburden Drilling Management Ltd .

Tills in the Star Lake area contain gold grains which are irregular or delicate in shape indicating short transport (<500 m). At the Rush Lake zone more than 80% of the grains are delicate within 75 m down-ice from the mineralized zone, whereas, from this point to the limits of the train 50% of the grains are irregular in shape. Similarly, at the 21 Zone more than 80% of the grains are delicate within 50 m of the deposit. Irregular grains dominate in the train 100 m from the source.

In the Tower Lake area, all gold grains are delicate or irregular. Samples closest to the presumed source contain greater than 80% delicate gold grains. In the remainder of the train the irregular grains predominate which conforms to the travel distance which is up to 600 m.

In the Waddy Lake area the gold grain count per bulk sample (4-8 kg) ranges from 1 to 89 with greater than 75 grains occurring in samples from known dispersion trains. The size of the grains ranges from < 50 μm to > 1500 μm with 70% less than 200 μm and only 3% greater than 500 μm. This reflects the fine grained nature of the gold in the bedrock.

DISPERSION TRAINS

In the Star Lake area, gold grain counts in till outline dispersion trains from the 21 Zone and Rush Lake mineralization. Ten particles or more define a train 75 m wide and at least 200 m down-ice from the 21 Zone. A train 300 m long and 75 m wide is outlined along the Rush Lake zone.

South of the Tower Lake structure a high background gold grain count (>10) indicates that the whole structure may be mineralized to varying degrees. A concentration of mineralization is the source of a dispersion train at least 500 m long and 200 m wide which contains more than 20 gold grains per bulk sample. Another potential train with elevated gold grain counts occurs at the western end of Tower Lake.

In the Waddy Lake area the dispersion trains contain irregular to delicate grains and indicate a transport distance of less than 500 m. Till composition, pebble lithology and shape support this interpretation. A good correlation between pebble lithology and bedrock exists with 70% of the samples traceable to a likely source within several hundred metres up-ice.

A dispersion train 50 metres by 800 metres composed of the Riddle and Gamble tills was outlined for the EP Zone with bulk samples containing over 100 gold grains. It was estimated that a mineralized source 200 m in length was required to explain the width of the dispersion train. Factors contributing to the high gold content of the till and the length of the dispersion train are the parallelism of the EP mineralization to the path of the glacial advance and the extreme softness of the chloritic shear that hosts the mineralization.

The gold grains in the Riddle, Kosta and Gamble tills were found to be of common size and to be much coarser than those near the Komis deposit. Originally, it was inferred that the Riddle, Kosta and Gamble till were exposures of a single, intermittently buried dispersion train. The degree of abrasion of the gold grains was found to increase systematically southward from

near-delicate in the Gamble till to irregular in the Riddle till and near-abraded in the Kosta till suggesting a source near the Gamble train. It was later demonstrated that the Gamble was not related to the same mineralization as the other two trains.

In the Komis area, the gold grains were found to be abraded indicating long transport. It was later established that the sample area was not directly down-ice from the Komis deposit, and the gold grains simply represented the regional till background.

In cases where rock-type, roundness and size of pebbles indicates greater transport distance the till material likely represents ablation or englacially transported material. In extremely large train consisting of shale pebbles derived from the Mesozoic deposits of Deep Bay with a length of over 100 km and over 50 km in width has been defined by W.G.Q. Johnston (in preparation). This is an unusual distribution pattern and may represent a surge of ice not typical of normal glacial basal transport.

GOLD ANALYSES IN TILL DEPOSITS

A number of analytical techniques have been compared using samples from different dispersion trains in the La Ronge Domain. These techniques include heavy mineral separation, gold grain counting, and geochemical analysis of various till fractions and are described in detail by Sopuck et al. (1986) and Campbell (1986). The results of these analyses and the conclusions drawn concerning the most effective analytical methods can be applied in a general way to the entire area.

At Star Lake, anomalous values in both the clay and the -180μm fractions occur only sporadically. The heavy mineral assays and the gold particle counts are clearly superior in their definition of the dispersion trains. A weak correlation exists between the gold contents of the heavy minerals, the clay, and the -180 μm fractions. Background gold contents for the clay and -180 μm fractions are 20 ppb and 5 ppb respectively.

At Tower Lake a moderate correlation exists between the gold contents of the heavy minerals, clay and -180 μm fraction of the till. The gold content of the heavy mineral concentrate and the gold grains themselves are superior in defining the dispersion trains. Background gold contents for the clays and -180 μm fractions are 20 ppb and 5 ppb respectively.

In the Waddy Lake area the majority of higher gold values correspond to the silty-sand till with the highest gold values associated with samples having a high silt content suggesting that the gold is fine grained. Seventy percent of the samples contain less than 20 ppb gold based on the analyses of 166 samples. This value is considered representative of background levels while some samples provide values greater than 100 ppb gold.

Gold contents in the heavy mineral concentrate were calculated using the dimensions of the observed gold grains assuming a thickness factor developed by Averill and Zimmerman (1984). These calculated values are generally within $\pm$50% of the gold analyses on the split of the heavy mineral fraction.

High calculated assays may be due to the "nugget effect" during splitting of the heavy mineral concentrate. Where assays are high and no visible gold was seen, the possibility is that the gold is very fine grained or that a few large grains where not detected on the table.

Another possibility is that the gold is included in other rock particles and is not detected visually. In fact, based on comparative results, it is estimated that in some samples up to 58% of gold may be combined. This latter case is justification for using the nondestructive neutron activation technique for gold analyses.

Duplicate analyses reveal that normalized gold contents and gold grain counts exhibit a precision to within $\pm$50%, whereas gold in the clay fraction shows a precision of $\pm$40%. Gold in the silt and clay size fraction is lost during the heavy mineral concentration procedure. However, in the study area it is estimated that the maximum gold loss attributable to clay loss during processing is less than 6% since the tills commonly contain less than 10% of this fine fraction.

Generally, analyses of bulk till samples are more representative than analysis of smaller samples. One problem in analyzing -180 μm material is the inability to differentiate physical gold from hydromorphically reconstituted gold. Many samples collected from oxidized till would potentially contain gold of both types.

Clifton et al. (1969) showed that 20 gold particles of similar size should be present in the analytical split to obtain an analysis that accurately reflects the gold content of the parent sample. The bulk till samples commonly meet this requirement.

It is necessary to analyse the fine fraction of the till samples due to the possibility of fine grained or occluded gold. Analyzing the $<$2.0mm fraction of the till may be most representative of the gold content. Comparing these results to the heavy mineral concentrates would help determine how much gold, if any, is lost during the heavy mineral procedure and which fractions contain the gold.

PROBLEMS AND SOLUTIONS FOR THE EXPLORATIONIST

The effectiveness of surface geochemical techniques is highly dependent on a proper understanding of the Quaternary geology of the area. The combination of mapping surficial deposits, determination of the stratigraphy and regional till sampling provides a framework for exploration surveys.

Throughout the area, bedrock and ground moraine (till) constitute 65-70% of the surface material. Both media can be used for geochemical sampling.

The most prevalent till in the area is a lower, grey, silty-sand till. This material is subglacially derived and has undergone relatively short transport distance. Variations in lithology reflect changes in the local bedrock source. Gold occurrence in this till can be traced most directly to its origin.

An upper, brown-to-grey, sandy till which is loosely compacted represents the ablation phase of the lower till. A thin, upper, brown, clayey-silt to sandy-silt till occurs very discontinuously in the area and is derived from a readvance of ice into the Lake Agassiz basin. Gold in these deposits has undergone long or multiple transport and is therefore difficult to trace back to its source.

Glacial Lake Agassiz as well as other more minor glacial lakes formerly covered most of the prospective domains. Lacustrine deposits of silt and clay inhibit drift prospecting by acting as a blanket covering anomalous bedrock and till such as the EP Zone at Waddy Lake (Averill and Zimmerman, 1984). This material contains no evidence of mineralization and impedes surficial geochemical surveys including soil, lake sediment, and biogeochemical surveys because they effectively seal off anomalous bedrock and till from any surface expression.

Lake Agassiz sediments of clayey-silt to sandy-silt cover extensive but discontinuous areas commonly below 427 m in elevation. The thickness of these sediments is highly variable ranging from <1 m to >10 m. Biogeochemical surveys may be effective if plant roots penetrate through the lacustrine deposits. Since the silty sediments retain moisture relatively well most roots will not go below this layer unless the material is very thin (<1 m).

Boulders, cobbles and pebbles are common in the silts especially those immediately overlying till and bedrock. Frost heave and ice-rafting would account for their presence. If these fragments are of a high concentration the silt may be misinterpreted to be a till deposit.

Organic deposits, depending on their thickness and extent, can inhibit geochemical surveys. Commonly the muskegs are underlain by glaciolacustrine silts and clays; however, if these deposits are less than one metre thick humus sampling can be effective in defining gold zones in bedrock (Rampton et al.,1984; and Sheehan and Gleeson, 1984).

Outwash sand and gravel commonly covers less than 5% of the area. It occurs in plains or as small ice-contact ridges and hummocky deposits associated with ablation during ice recession or within and adjacent to fluvial channels. These stratified heavy mineral-rich deposits occur at various depths commonly from 5 to greater than 20 metres. Regionally, this type of deposit may form the B horizon of the soil profile and have been sampled in past soil surveys. These materials mask underlying anomalous till and bedrock. Anomalies may be due to the concentration of heavy minerals by water action and can be far from their source. Collection of a combination of fluvial and till samples would greatly complicate the interpretation of a geochemical survey in any area.

Bedrock topography is important in controlling ice transport distance and direction, and causes great variability in drift thickness. Bedrock knobs tend to deflect or channel local ice movement and restrict transport while lows tend to concentrate thicker deposits of drift.

Local ice direction is critical in determining the pathway that the trace mineralization has travelled. Another important factor is the angle at which the ice direction intersects the mineralized structures. If the ice-flow direction intersects linear mineral structures at a high angle the resultant dispersion train will be broad and poorly focused. If the ice-flow direction is parallel to linear mineral structures then the resultant dispersion train will be narrow and distinct. Variations in the ice-flow intersection angle as well as the form of the mineral structures will create quite different dispersion patterns.

Translocation (downward movement) of silt from the upper part of the soil profile to the lower part of the B horizon and the C horizon by pedogenic (soil forming) process has been noted in the region. This process is manifested by a heavy silt coating on the upper side of pebbles in the C horizon. This translocation likely effects gold concentrations; however, the actual affects are not known for certain at this time.

Gold in till is mainly fine grained reflecting the fine grained nature of the source deposits. Grains are commonly irregular to delicate in dispersion trains indicating short transport distance.

Dispersion trains are defined in till samples by 10 or more gold grains per sample or by values of 4g/tonne gold or greater in the heavy mineral concentrate. The dispersion trains are 75-100 m wide and at least 300 m long and can be delineated by less than 100 sample sites in a 2 km^2 area.

Heavy mineral counts and descriptions of gold grains is a direct approach to finding significant gold concentrations in till and characterizing the gold with respect to distance from the source and style of mineralization. Minimum size for bulk till samples is 4 kg; however, larger samples up to 8 kg provide more consistent results.

Analyses of the clay fraction provides relatively indirect geochemical information. Analysis of the finer fractions of the till offers promise in detailed follow-up surveys, once the dispersion train or mineralization has been identified, particularly in mineralized tills characterized by abundant gold in the fine sand and silt size ranges. The silt and clay component is the most homogeneous sampling media when fine gold constitutes the mineralization. However, small samples of the clay and -180 μm fractions are not as useful as the heavy mineral concentrate from bulk till samples in depicting dispersion trains at greater distances from the source.

Associated pathfinder elements such as arsenic are useful in some surveys involving small till samples or biocheochemical methods; however, gold itself appears to be the best pathfinder to gold mineralization.

From 9 to 65% of the gold may be lost during the heavy mineral concentration procedure. In the study area, gold in clay loss is not likely to exceed 6% since clay contents in basal tills seldom exceed 10%.

Most of the gold loss can be accounted for by occluded gold probably in quartz and not separable by gravity means. Combined gold can range from 34 to 58%. Loss of free gold grains on the shaking table is negligible.

An analysis of the fine fraction of the till is recommended as an inexpensive step in addition to the collection of a bulk till sample and subsequent heavy mineral concentration and analysis.

DISCUSSION AND RECOMMENDATIONS

The success of drift prospecting is highly dependent on a proper understanding of the Quaternary geology; that is, determining the drift deposits, their characteristics, their origin and significance to prospecting. The first phase of any work in an area should involve the mapping of the area by areial photograph interpretation followed by field verification. This mapping should be at a maximum scale of 1:20,000.

Information concerning the sub-surface is required for a proper interpretation of the Quaternary setting. A number of techniques could be used to provide this data. Power drilling with such equipment as a reverse circulation or sonic drill would ensure complete penetration and would provide representative samples of the drift as well as a sample of the underlying bedrock.

Other methods such as power augering or "Wacker" drilling may provide reasonable but relatively small samples of the drift but will not always be able to penetrate to bedrock because of excessive thickness of the drift, the type of drift, or the presence of large boulders.

The large equipment power drilling methods are effective; however, they are costly and the equipment is difficult to mobilize; two factors which may inhibit the use of such techniques.

Alternatively, pits or trenches can be dug by hand or by backhoe. Such holes can be dug 1-2 metres deep in a short time. In many cases this depth will enable access to the lower till and provide valuable sub-surface information. Later, test drilling at key sites or where drift is excessively thick or impenetrable could be used to provide the complete stratigraphy.

The direction and distance of transport of material are critical factors to drift prospecting. Landforms such as drumlins, flutings, crag-and-tail, roche moutonnee along with striations, crescentic marks, and other gouges in bedrock can reveal the direction of the last ice movement or of previous glaciations. Till fabrics signify the direction of movement of the ice that deposited the till material and can also be used as an identifying parameter in some cases.

Till pebble lithology and the degree of rounding or comminution of rocks and minerals in the till can be used as criteria to determine the direction and distance of transport. Surface geochemical methods should work well above the lacustrine level of about 427 m in most of the prospective area of the southeastern Shield. Lacustrine sediments, organic deposits and fluvial materials should not be sampled in such surveys or must be clearly identified if sampled to avoid confusion in interpretation of results.

The lower or basal till which is commonly a grey, silt-sand till should be sampled for analysis. Samples should be collected from the C soil horizon (>1 m depth) to avoid the effects of the pedological (soil forming) processes such as translocation, oxidation, and leaching which are operating in the upper part of the profile.

The upper, readvance or ablation till, which may be clay-rich or very sandy should not be confused with the other till, since it does not likely resemble the underlying till or bedrock and a meaningful distance and direction of transport is difficult to determine.

In areas where the silt and clay cover is less than

1.5 m thick, pits could be excavated to intersect the lower till unit. Large areas of the prospective volcanic belts are covered with a thick blanket of silts and clays. The only effective way to test these areas is to employ overburden drilling and sampling equipment. This equipment should be able to penetrate up to 15 m of combined lacustrine and fluvial material as well as boulder layers and several metres of till.

Analyses such as grain size determination, clay mineral identification, pebble counts, and till fabric analyses can be done to help characterize the various till deposits. Geochemical analyses of tills for trace metals and gold can provide other criteria for differentiating between tills while also indicating anomalies.

Gold itself is the most direct pathfinder for tracing gold in drift back to its source in bedrock. Large representative samples, from 4 to 8 kg, of the lower till should be collected for bulk till analyses which should include heavy mineral separation, gold grain counts and identification. An analysis of the fine fraction of the till is recommended as an inexpensive step in addition to the bulk till analyses.

Gold grain counts define dispersion trains which are commonly 75-100 m wide and 300 m long while the shape of grains indicates the distance from the source. Approximately 100 samples evenly distributed within a few square kilometres will normally define a dispersion train.

Geochemical analyses of the various till fractions, particularly the clay fraction, will help determine the nature of the gold in the drift and indicate the style of mineralization of the source deposit.

REFERENCES

Averill, S.A. and Zimmerman, J.R., 1984. The Riddle resolved: the discovery of the Partridge gold zone using sonic drilling in glacial overburden at Waddy Lake, Saskatchewan. Canadian Geological Journal of CIM, no. 1, p14-20.

Bostock, H.S., 1970. Physiographic subdivisions of Canada. *in* Geology and Economic Minerals of Canada, ed. R.J.W. Douglas. Geological Survey of Canada, Economic Geology Report 1, p10-30, map.

Byers, A.R., 1948. The geology of the Waddy Lake area. Department of Mineral Resources, Province of Saskatchewan, Preliminary Report, no.1, 36p.

Campbell, J.E., 1986. Quarternary geology of the Waddy Lake area applied to prospecting for gold. Saskatchewan Research Council Report, R-842-1-E-86, 74p, map.

Canada Soil Survey Committee, Subcommittee on Soil Classification, 1978. The Canadian system of soil classification. Canada Department of Agriculture, Publication 1646. Supply and Services Canada, Ottawa, Ont. 164p.

Christiansen, E.A., 1956. Glacial geology of the Moose Mountain area, Saskatchewan. Saskatchewan Department of Mineral Resources, Report 21, 35p.

Christiansen, E.A., 1979. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal Earth Science, v16, no.4, p913-938.

Christiansen, E.A. and Whitaker, S.H., 1976. Glacial thrusting of drift and bedrock. *in* Glacial Till, An Inter-disciplinary study, ed. R.F. Legget. Royal Society of Canada, Special Publication no.12, p121-130.

Clayton, J.S., Ehrlich, W.A., Cann, D.B., Day, J.H. and Marshall, I.B., 1977. Soils of Canada. Agriculture Canada Research Branch, v1, 243p and v2, 239p.

Clayton, L. and Moran, S.R., 1974. A glacial process-form model. *in* Glacial Geomorphology, ed. D.R. Coates. Published in Geomorphology, State University New York, Binghamton, New York, p89-119.

Clifton, H.E., Hunter, R.E., Swanson, F.J. and Phillips, R.L., 1969. Sample size and meaningful gold analysis. United States Geological Survey Professional Paper 625-c.

Coombe, W., 1984. Gold in Saskatchewan. Saskatchewan Energy Mines, Saskatchewan Geological Survey, Open File Report 84-1, 134p.

Dreimanis, A. 1976. Tills: their origin and properties. *in* Glacial Till, An Inter-disciplinary Study, ed. R.F. Legget. Royal Society of Canada, Special Publication 12, p11-49.

E.A. Christiansen Consulting Ltd., 1977. Quaternary geology of the Stanley Mission area, Saskatchewan. *in* Stanley Mission School Sewer and Water Study Report, Saskmont Engineering Co. Ltd.

Elson, J.A., 1967. Geology of Lake Agassiz. *in* Life Land and Water: Proceedings of the 1966 Conference on Environmental Studies of the Glacial Lake Agassiz Region, ed. W.J. Mayer-Oakes. University of Manitoba Press, Winnipeg, p37-96.

Fairbridge, R.W., ed. 1968. The Encyclopedia of Geomorphology. Reinhold Book Corp., N.Y., Encyclopedia of Earth Science Series, v3, 1295p.

Fenton, M.M., Moran, S.R., Teller, J.T. and Clayton, L. 1983. Quaternary stratigraphy and history in the southern part of the Lake Agassiz basin. *in* Glacial Lake Agassiz, ed. J.T. Teller and L. Clayton. Geological Association of Canada Special Paper 26, p49-74.

Goldthwait, R.P., 1971. An Introduction to Till, Today. *in* Till: A Symposium, ed. R.P. Goldthwait. Ohio State University Press, Columbus, p3-26.

Harper, C.T., 1984. Geological mapping, Waddy Lake area (Part of NTS 64D-4 and -5). *in* Summary of Investigations 1984, Saskatchewan Geological Survey, Miscellaneous Report 84-4, p6-20.

Hornbrook, E.H.W. and Garrett, R.G., 1976. Regional geochemical lake sediment survey, east-central Saskatchewan. Geological Survey of Canada, Paper 75-41, 70p.

Hornbrook, E.H.W., Garrett, R.G., Lynch, J.J. and Beck, L.S., 1975. Regional lake sediment geochemical reconnaissance data, east-central Saskatchewan (NTS 63M, 64D and part of 63K, 63L, 73I, 73O, 73P and 74A). Geological Survey of Canada Open File 266, 52 maps, 108p.

Johnston, W.A., 1916. The genesis of Lake Agassiz. Journal of Geology, v24, p625-638.

Johnston, W.A. 1946. Glacial Lake Agassiz, with special reference to the mode of deformation of the beaches. Geological Survey of Canada, Bulletin 7, 20p.

Johnston, W.G.Q., 1978. Lake Agassiz's northernmost arm and other features of the Quaternary geology in the region around the southern part of Reindeer Lake, northern Saskatchewan, Musk-Ox, University of Saskatchewan, no.21, p39-50.

Kidd, R., 1979. Gold property, Waddy Lake Resources Inc., Reindeer Lake area, Saskatchewan. Confidential report of Waddy Lake Resources, 19p.

Kupsch, W.O., 1962. Ice-thrust ridges in western Canada. Journal of Geology, no.5, p582-594.

Kupsch, W.O., 1969. Glacial geology (Quaternary) of Saskatchewan. *in* Atlas of Saskatchewan, ed. J.H. Richards and K.I. Fung. University of Saskatchewan, p48-51.

Kupsch, W.O., 1975. The Churchill-Reindeer Rivers area: Evolution of its landscape. University of Saskatchewan, Musk-Ox, no. 15, p10-29.

Langford, F.F., 1973. The geology of the Wapawekka area, Saskatchewan. Saskatchewan Department of Mineral Resources, Report 147, 36p.

Langford, F.F., 1975. Geology, Churchill River Study (Missinipe Probe). Churchill River Study, Saskatoon, Final Report 17, 131p.

Langford, F.F., 1977. Northern extent of Lake Agassiz in eastern Saskatchewan. Canadian Journal Earth Science, v14, no.6, p1286-1291.

Lewry, J.F. and Sibbald, T.I.I., 1977. Variation in lithology and tectonometamorphic relationships in the Precambrian basement of northern Saskatchewan. Canadian Journal Earth Science, v14, p1453-1467.

Lewry, J.F. and Sibbald, T.I.I., 1980. Thermotectonic evolution of the Churchill Province in northern Saskatchewan. Tectonophysics, v68, p45-82.

Lewry, J.F., Sibbald, T.I.I. and Rees, C.J., 1978. Metamorphic patterns and their relationship to tectonism and plutonism in the Churchill Province. *in* Metamorphism in the Canadian Shield, ed. J.A. Fraser and W.W. Heywood. Geological Survey Canada, Paper 78-10, p139-154.

Macdonald, R. and Broughton, P., 1980. Geological map of Saskatchewan, provisional edition. Saskatchewan Department of Mineral Resources, scale 1:1,000,000.

Prest, V.K., 1970. Quaternary geology of Canada. *in* Geology and Economic Minerals of Canada, ed. R.J.W. Douglas. Geological Survey of Canada, Economic Geology Report 1, p676-764.

Prest, V.K. Grant, D.R. and Rampton, V.N., 1968, Glacial map of Canada. Geological Survey of Canada, Map 1253A, scale 1:5,000,000.

Price, R.J., 1973. Glacial and fluvio-glacial landforms. *in* Geomorphology Texts, ed. K.M. Clayton. Oliver and Boyd, Edinburgh, 242p.

Rampton, V.N., Gleeson, C.F., Thomas, R.D. and Paradis, S., 1984. Geochemical exploration in areas of shallow tills. A paper presented to the CIM-OGS Till Tomorrow'84, Kirkland Lake, Ontario, May 8-12, 1984.

Robertson, R.H., 1978. Geological factors in the development of streams and their whitewater reaches on the Precambrian Shield, northern Saskatchewan. Unpublished M.Sc. thesis, University of Saskatchewan, Saskatoon, 241p.

Schreiner, B.T., 1983. Lake Agassiz in Saskatchewan. *in* Glacial Lake Agassiz, ed. J.T. Teller and L. Clayton. Geological Association of Canada Special Paper 26, p75-96.

Schreiner, B.T., 1984. Quaternary geology of the Precambrian Shield, Saskatchewan. Saskatchewan Energy and Mines, Report 221, 106p.

Schreiner, B.T. and Alley, D.W., 1975. Quaternary geology, Lac La Ronge area (73P), Saskatchewan. Saskatchewan Research Council, Geology Division, DREE Quaternary North Program, Preliminary Map 1.

Schreiner, B.T., Alley, D.W. and McNamara, S.J., 1984. Quaternary geology of the Precambrian Shield, Saskatchewan. Saskatchewan Energy Mines, Open File Report 84-2 to 84-21, (series of 1:250 000 scale maps with marginal notes).

Shawinigan Engineering Co. Ltd., 1973. Wintego Development, feasibility study, technical report. Unpublished report for Saskatchewan Power Corporation.

Sheehan, D. and Gleeson, C.F., 1984. Case histories of till prospecting over the Doyon, Bousquet and Williams gold deposits. A paper presented to the CIM-OGS Till Tomorrow'84, Kirkland Lake, Ontario, May 8-12, 1984.

Sopuck, V.J., Lehto, D.A.W. and Alley, D.W., 1977. Uranium dispersion studies, Maguire Lake area. *in* Summary of Investigations 1977; Saskatchewan Geological Survey, ed. J.E. Christopher and R. Macdonald. Saskatchewan Department of Mineral Resources, p60-68.

Sopuck, V.J., Lehto, D.A.W. Schreiner, B.T., and Smith, J.W.J., 1980. Interpretation of reconnaissance lake sediment data in the Precambrian Shield area, Saskatchewan. Saskatchewan Research Council Report G-78-10a, 53p.

Sopuck, V.J., Schreiner, B.T. and Averill, S.A., 1986. Drift prospecting for gold in Saskatchewan. A paper presented to the Canadian Institute of Mining and Metallurgy Symposium - Gold in the Western Shield, Saskatoon, September, 1985, 23p (plus figures).

Tyrrell, J.B., 1896. The genesis of Lake Agassiz. Journal of Geology, v4, no.7, p811-815.

Upham, W., 1895. The glacial Lake Agassiz. United States Geological Survey, Monogram, 25, 658p.

Wilson, M.A., 1981. The climatic and vegetational history of the postglacial in central Saskatchewan. Unpublished Ph.D. thesis, University of Saskatchewan, Saskatoon, 189p.